農藥施噴品質量測與管制研討會論文集

Proceedings of Conference on Measurement and Management of Agrochemical Spraying Quality

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台灣省農業試驗所編印

中華民國八十七年十二月

Taiwan Agricultural Research Institute

Taichung, Taiwan 413, ROC.

December, 1998

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Proceedings of Conference on
Measurement and Management of Agrochemical Spraying Quality

台灣省農業試驗所國際會議廳 台中 霧峰

中華民國 87 年 12 月 17 日至 18 日

Taiwan Agricultural Research Institute

Taichung, Taiwan 413, ROC.

December 17-18, 1998

台灣省農業試驗所	主辦
行政院農業委員會	輔導
台灣省政府農林廳	輔導
台灣大學農業機械工程系	協辦
中興大學農業機械工程系	協辦
嘉義技術學院農業機械工程技術系	協辦

001160

台灣省農業試驗所編印

中華民國八十七年十二月

序

臺灣地處亞熱帶及熱帶，氣候高溫多溼，農作物集約栽培，病蟲害種類繁多，且容易滋生蔓延，為確保農作物產量並保持優良品質，農藥及肥料之施用實難以避免，然而在此地狹人稠之臺灣，使用農業化學用品所引發之污染問題常為社會大眾所關切，因此，如何有效且安全地使用農業化學用品，並兼顧農業生產及環境保護，實為當務之急及共同努力之目標。

以往國內在農業化學用品施用機械方面之研究與發展，因要求速效而有偏重國外優良機種之引進與本土適用化改良之趨勢，較少基礎性之自主研發，因此至今對於農業化學用品施用品質之評量仍無適當可用之技術，反觀國外，由農業化學用品施用機械作業性能之提升、農業化學用品施用污染之評估與防制，以至於精準控制農業化學用品施用數量於固定位置之精耕農業技術，均能循序漸進作深入研究，尤其，近年來拜通訊衛星之便利精耕農業技術之研究更如火如荼地展開，且已有商品化產品上市，此種情勢實值得我們進一步深思並及早籌謀適當之因應對策。

隨著社會大眾對於環保要求之與日俱增，為減少農業化學用品施用之次數與數量，農業化學用品施用必須被視為一項有價值之策略且只於需要時才被使用，因此，判定農業化學用品施用效能與配套量測非目標飄移之相關技術日益突顯其重要性。有鑑於國內相關技術與資料仍付闕如，本研討會特邀請國外專家來臺就相關技術作專題演講，其除可提供國內相關技術研發時參考外，更加強相關人員意見交流的機會，冀望其對提升國內農藥施噴品質及防杜不當農藥飄移問題之產生有所助益。

台灣省農業試驗所
所長　林俊義

林俊義謹識
中華民國八十七年十二月七日

農藥施噴品質量測與管制研討會議程

Agenda of the Workshop on Measurement and Management of Agrochemical Spraying Quality

第一天 1998 年 12 月 17 日(Day 1)

08：30~09：00 報到 (Registration)

09：00~09：30 開幕 (Opening Ceremony)

09：30~09：40 團體合影 (Group Photograph)

09：40~10：10 專題演講(一) (Presentation I)

主講人 (Speaker)：鄭允博士 (Dr. Edward-Yun Cheng)

講題 (Topic)：農藥安全施用與殘留管制

(Safe chemical application and residue control.)

10：10~10：30 茶點 (Coffee/Tea Break)

10：30~12：00 專題演講(二) (Presentation II)

主講人 (Speaker)：Dr. H. Erdal Ozkan

翻譯人 (Translator)：李允中博士 (Dr. Yeun-Chung Lee)

講題 (Topic)：有效農藥施噴與減低農藥浪費

(Effective Pesticide Application and Reducing Pesticide Waste.)

12：00~13：30 午餐——請至行政大樓三樓大禮堂用餐 (Lunch Break)

13：30~15：00 專題演講(三) (Presentation III)

第一節 (First Session)

主講人 (Speaker)：Dr. H. Erdal Ozkan

翻譯人 (Translator)：林正亮博士 (Dr. Jeng-Liang Lin)

講題 (Topic)：美國農藥施噴之最新發展

(Recent Trends in Agrichemical Application in the USA)

第二節 (Second Session)

主講人 (Speaker)：Dr. Robert D. Fox

翻譯人 (Translator)：林正亮博士 (Dr. Jeng-Liang Lin)

講題 (Topic)：俄亥俄州與美國農藥施噴技術之研究

(Research on Application Technology in Ohio and the U.S.A.)

15：00~15：20 茶點 (Coffee/Tea Break)

15：20~16：50 專題演講(四) (Presentation IV)

主講人 (Speaker)：Dr. Robert D. Fox

翻譯人 (Translator)：謝禮丞博士 (Dr. Li-Cheng Hsieh)

講題 (Topic)：霧滴與葉表交互作用(包括介面活化劑與飄移減低聚合物之效用)之研究
(Droplet/leaf Surface Interaction Studies, including Effects of Surfactants and Drift Reduction Polymers.)

第二天 1998 年 12 月 18 日 (Day 2)

08：30~10：00 專題演講(五) (Presentation V)
主講人 (Speaker)：Dr. Robert D. Fox
翻譯人 (Translator)：林正亮博士 (Dr. Jeng-Liang Lin)
講題 (Topic)：農藥施噴品質判定之方法與技術
(Methods and Techniques in Determining Spray Quality.)

10：00~10：20 茶點 (Coffee/Tea Break)

10：20~11：50 專題演講(六) (Presentation VI)
第一節 (First Session)
主講人 (Speaker)：Dr. Robert D. Fox
翻譯人 (Translator)：謝禮丞博士 (Dr. Li-Cheng Hsieh)
講題 (Topic)：噴霧飄移數量量測之方法與技術
(Methods and Techniques in Measuring Spray Drift.)
第二節 (Second Session)
主講人 (Speaker)：Dr. H. Erdal Ozkan
翻譯人 (Translator)：謝禮丞博士 (Dr. Li-Cheng Hsieh)
講題 (Topic)：減低噴霧飄移之方法
(Methods of Reducing Spray Drift.)

11：50~13：30 午餐——請至行政大樓三樓大禮堂用餐 (Lunch Break)

13：30~15：00 專題演講(七) (Presentation VII)
第一節 (First Session)
主講人 (Speaker)：Dr. H. Erdal Ozkan
翻譯人 (Translator)：李允中博士 (Dr. Yeun-Chung Lee)
講題 (Topic)：歐美施藥機械之測定與認証
(Sprayer Testing and Certification Programs in the USA and Europe)
第二節 (Second Session)
主講人 (Speaker)：Dr. H. Erdal Ozkan
翻譯人 (Translator)：李允中博士 (Dr. Yeun-Chung Lee)
講題 (Topic)：毆美農藥施噴人員之發照與教育
(Licensing and Education of Applicator in the USA and Europe)

第三節 (Third Session)

主講人 (Speaker)：Dr. H. Erdal Ozkan

翻譯人 (Translator)：李允中博士 (Dr. Yeun-Chung Lee)

講題 (Topic)：美國精耕農業之現況

(Current Status of Precision Farming in the USA.)

15：00~15：20 茶點 (Coffee/Tea Break)

15：20~16：50 綜合討論 (General Discussion)

主持人(Moderator)：林所長俊義 (Dr. Chien-Yih Lin)

15：20~15：35 引言一 (Introductory Remark I)

引言人 (Speaker)：盛中德博士 (Dr. Chung-Teh Sheng)

講題 (Topic)：國內農藥施噴機械研發現況與未來方向

(Current research and development of spraying machines in Taiwan and future trends.)

15：35~15：50 引言二 (Introductory Remark II)

引言人 (Speaker)：宮台華小姐 (Ms. Tai-Hwa Kung)

講題 (Topic)：國內農藥施噴人員証照制度

(Licensing of Applicator in Taiwan.)

15：50~16：50 問題與討論 (Questions and Discussion)

中心議題：

一、臺灣病蟲害防治機械與技術之未來研究方向？

二、如何以團隊合作方式進行病蟲害防治機械與技術之研發工作？

三、臺灣應有怎樣的制度來管理施藥機械之測定與認證，以及施噴人員之證照與教育？

四、臺灣是否適合發展精耕農業(precision farming)？可能的應用目標應定在那裏？

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農藥安全施用與殘留管制

鄭 允、高靜華

農藥施用時，其安全性的考量與作物的種類有極大的關係。長期性的農藝作物因季節性明顯，病蟲害的種類較為明確，如水稻一期與二期之褐飛蝨、稻縱捲葉蟲及稻熱病等，皆有固定的發生時期與環境條件，因此用藥的對象明確，且因採收後至食用或經加工的期間較長，無論藥劑的使用及農藥殘毒之管制上均易於控制。唯有其栽培環境中經水或土壤的污染，較可能造成長期累積性的安全顧慮，如重金屬，惟並不在此次研討議題範圍，故不多作討論。

消費大眾顧慮的農藥殘毒問題，多集中在園藝作物，如短期的蔬菜及結果期的水果。由於園藝作物收穫時間短，價值高，多屬鮮食，其外觀對價格影響極大，在病蟲害的考量上需兼顧食用價值與外觀的完美，因此促使農民在進行病蟲防治時，措施嚴密，且以預防為主，以確保收穫產品的市場價值。在本省更由於地處亞熱帶，蔬果生產與病蟲害發生的重疊性大，季節性的影響低，隨時都有施用農藥的需要，蔬果遂成為農藥安全使用及殘毒管制上最困難的作物群。蔬果上常使用的藥劑以殺蟲劑及殺菌劑為主，其中，殺蟲劑即包括了有機磷劑、氨基甲酸鹽、除蟲菊精、昆蟲長調節劑、微生物製劑以及各類新發展的藥劑如阿巴汀等，因殺蟲劑對哺乳類的直接毒害較高，目前為殘毒管制之主要項目。殺菌劑以保護劑如大生類(EBDC's)，以及治療劑如億力(Benlate)等為大宗，對人體的為害雖較殺蟲劑為低，但其中大生類所含之不純物及代謝物 ETU 具致癌性，故其殘毒亦受到管制。

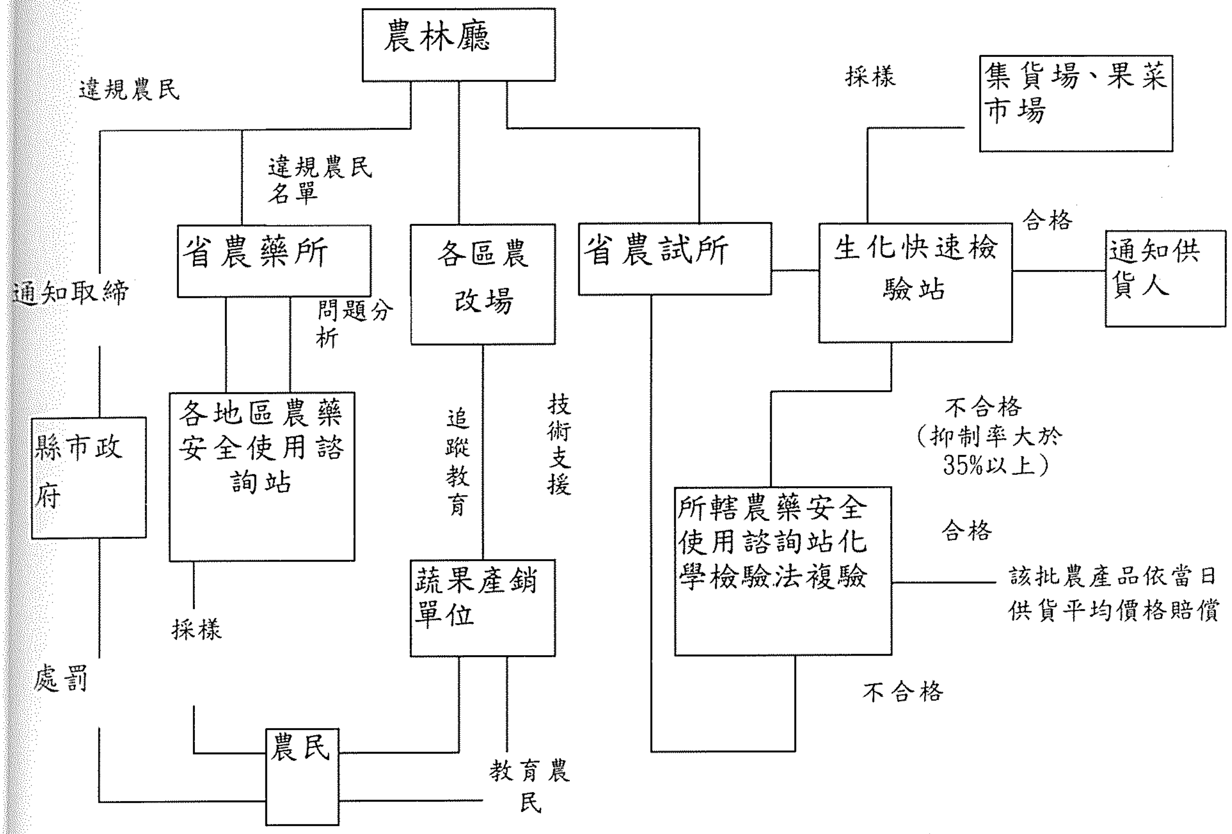
造成農藥安全使用上之另一項困擾，則為病蟲害的抗藥性問題。由於藥劑的連續使用會造成生物體產生抗性，導致藥劑依推薦濃度使用時，仍無達到防治效果，一旦農民對所使用的藥劑產生疑問，則以混用及提高劑量等方式施用藥劑，殘毒問題亦隨之而來。目前，國內的抗藥性研究非常活躍，也已經有具體的成果，如小菜蛾抗藥性及其防治對策的研究，就針對十字花科蔬菜害蟲之藥劑採用輪用藥劑策略，在 37 個農會進行田間示範，培訓 137 位核心農民為田間講員，將抗藥性問題及解決方法介紹給農

民，使此一簡化用藥之防治策略能落實基層。使用毒性藥劑所造成的安全顧慮，主要為殘毒問題，兩大病因之一為：農民仍將農藥視為毒藥(Toxin)，施用後只要能將病蟲害一掃而光，就認為是滿意的防治效果，而未將農藥視為治療性的藥劑(Medicine)，在認清病蟲害後才對症下藥，以致混用農藥、提高劑量等現象極為普遍，因之也造成了第二個問題：正確的藥劑因混用他種藥劑而導致用量不足，而不該使用的藥劑也被亂用，造成金錢浪費及殘毒問題，更有其他的副作用，如：導致抗藥性的發生、造成有益天敵及非目標生物的死亡等。因此落實教育農民確認病蟲害種類，選擇正確的藥劑，以及恰當的施藥技術(包括適當的施藥器材、正確的配方及施藥方法)，應可大幅降低殘毒問題，提昇農產品的安全品質。

農藥安全及殘毒管制方面，生產期長的糧食作物如稻穀穀、玉米等，由於貯存期長，以監測及預檢方式即可達到管制殘毒超量的目的；而栽培期短之蔬果類，其農藥之使用及殘毒管制則特別受到重視，除了植物保護手冊內詳細規範農藥的使用方法及注意事項外，近年來農林廳更規劃了蔬菜安全區，由政府督導蔬果密集生產地區，依照已推廣之植物保護技術及病蟲害防治曆進行用藥，並對即將採收之蔬果則進行田間農藥殘毒之預檢。近年來，更以吉園圃的認證制度，篩選能安全用藥且殘毒合於規定之生產班，提供消費者另一種選擇。多年來，農委會及農林廳在「農藥殘留監測與管制計畫」項下，建立了蔬果農藥殘毒管制體系(如圖一)，對台灣省及北高兩市生產及運銷之蔬果品質，進行監測及預檢把關，期能減少殘毒問題之發生。

國內在蔬果採收後及上市前，另有一套快速的毒性檢測體系，可對已採收上市之蔬果進行即時的殘毒管制。此一體系係應用台灣省農業試驗所研發之技術，輔導各蔬菜產區農會及果菜市場設置檢驗站，對含毒超量之蔬果進行監控；另外，快速檢驗在消費型的都會區以及生鮮業之連鎖超市亦受到重視，並經採用為控管農藥殘毒的標準工作體系。

農產品農藥殘留防止工作體系流程



(化學檢驗)　　　　　（生化快速檢驗）

APPLYING PESTICIDES EFFICIENTLY

H. Erdal Ozkan Robert D. Fox[1]

ABSTRACT

Pesticide manufacturers spend large amounts of time and money to determine the recommended application rate for pesticides. The recommended rate must be large enough to control the target pests under most field conditions, but must be as low as possible so use of the pesticide is as economical as possible for the farmer. The effect of pesticides are greatly influenced by the method and timing of application and the operation and accuracy of the equipment used. Applying too little pesticide causes ineffective pest control that may require the added expense of respraying. Applying too much pesticide adds to the cost, may damage the crop, and may lead to environmental pollution. Labels on pesticide containers indicate proper application rates. However, these rates can be achieved only if the application equipment is suitable for the job, calibrated frequently, and operated properly.

Achieving satisfactory results from pesticides depends heavily on five major factors:

1. Positive identification of the pest. Make sure you know which pest you're trying to control before filling the sprayer tank with pesticides.
2. Using the right pesticide. Choose a pesticide that will work.
3. Selecting the right equipment, and particularly the right type and size of nozzle for the job.
4. Applying pesticides accurately at the right time.
5. Maintaining spray equipment in good condition. Individual components of the equipment should be checked periodically to make sure that you are applying the amount recommended on the chemical label.

This article suggests techniques to achieve maximum accuracy and efficiency in liquid pesticide application

Guidelines for Effective Spraying

Once the pest is identified and a pesticide selected, the next step is to make sure the right equipment is available to apply the pesticide at the proper rate to

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achieve satisfactory pest control. Many types of equipment may be used for applying different pesticides. An applicator can choose the best equipment depending on **a)** the time of application (pre-emergence, post-emergence, pre-plant incorporated) **b)** the growth stage of the target sprayed (young crops vs. established crops), and **c)** the physical shape and size of vegetation dominant within the application site (field or vegetable crops, trees, shrubs, grass, etc.). The applicator must make the final decision on selection of application equipment, its maintenance, operation and calibration, all of which can significantly affect application of pesticides at recommended rates.

The only way to determine whether or not a sprayer is actually applying a chemical at the recommended rate is to calibrate the sprayer. Regulatory guidelines in the U.S. indicate that the application should be within 5% of the recommended label rate. Evaluation of 152 private and commercial pesticide applicators in Nebraska revealed that only one out of four farmers were applying pesticides within 5% of their estimated rate (Rider and Dickey, 1982). A follow-up field survey of 103 private pesticide applicators indicated that only 30% of the cooperators were applying herbicides within 5% of their intended application rate. Twenty-six percent of the cooperators over-applied herbicides during a single application, with an average cost due to misapplication of $3.11/ha (Grisso et al., 1989). A survey conducted in South Carolina indicated that nearly 85% of applicators applied pesticides with error rates greater than 10% when compared to intended rates (Wolak, 1989). Hofman and Hauck (1983) reported that only 11 of the 60 sprayers they calibrated in North Dakota were applying chemicals within 10% of what the operator predicted. Calibration clinics conducted in Iowa and Ohio revealed that only 20 percent of sprayers tested were capable of applying a tank-mix within $\pm$ 5% of the intended application rate (Ozkan, 1987). Similar findings were reported from calibration clinics conducted in Montana and Colorado.

Although the survey results are limited to a small number of states, the data indicate that pesticide application accuracy continues to be problem regardless of the geographic location, and efforts to educate pesticide applicators should continue.

How uniformly the chemical is deposited on the target is as important as the amount deposited. Non uniform coverage can result from simple reasons such as using misaligned or clogged nozzles, nozzles with different fan angles, or from variation in distance from the ground or target crop canopy across the boom. These common problems result in streaks, untreated areas, or over-application of chemicals.

Below is a brief summary of guidelines to follow to produce an effective spraying job.

* Make sure all vital parts of the sprayer are functioning properly. Check for leaks. Check to see if the framework of the sprayer is structurally strong and secured to its carrier.

* Use water that looks clean enough to drink. Most problems with sprayer operation can be traced to foreign material in the water. Debris clog screens and wear out nozzles and pumps. Filter any water pumped from ditches, ponds, or lakes before filling the tank.

* One application rate is not recommended for all application situations. For example, in orchard applications, different rates are recommended depending on the tree canopy density, or for soil applied herbicides, different rates are recommended depending on the soil type. Therefore, always read the pesticide label to determine the proper application rate for your specific need.

* Mix the chemical in sufficient liquid carrier to apply the recommended coverage uniformly over the sprayed area. You must to be able to calculate the exact amount of actual chemical required for the spray solution in order to satisfy the label requirement. That means you must to be able to understand and follow recommendations written on the label. The application rate of a product, given on the label, is always expressed in terms of amount of product per hectare. However, because tanks come in different sizes, it is the responsibility of the applicator to determine the amount of product to be added to a full sprayer tank of water. Label instructions can be confusing. Allow time to double-check your calculations.

  Here is an example of the type of tank mixing situations you will come across. You have a 400 liter tank, your application rate is 40 liters per hectare, and the pesticide rate recommended is 4 liters per hectare. Therefore you need to apply 4 liters of pesticide in 40 liters of tank mix. How much pesticide formulation should you put in this tank filled with water? The answer is 40 liters.

* For accuracy, you must know how much water the tank will hold. For example, a tank rated at 200 liters may actually hold 210 liters when slightly overfilled. The assumption that tank markings are accurate, in this example case, can cause a 5% under application of the active ingredient. Don't rely on the tank markings. Carefully measure how much the tank contains. This can be done either by using a flowmeter or by weighing the sprayer on a scale when the tank is empty and full, and then converting the difference in weight to liters of water.

* You need to check the performance of each sprayer component prior to mixing chemicals to make sure they are performing satisfactorily. Don't under-estimate the importance of a single component. For example, many applicators consider the importance of an agitator in pesticide application equipment. Insufficient agitation may be a big problem with large tanks. This problem is most serious when applying pesticides formulated as wettable powders. If there are "dead spots" or sharp corners in the tank then insufficient agitation may allow wettable powders to settle to the bottom of the tank. In other cases, dry pesticides may float on the surface for a long time before mixing uniformly throughout the tank. As a result, the mixture sprayed may contain varying amounts of active ingredient at different times during the spray operation causing some areas to receive excessive amounts of pesticides, while other areas receive inadequate amounts.

* Select nozzles that provide the desired droplet size, flow rate, and pattern. Mount nozzles securely into position.

* Periodically, observe the output pattern of the nozzles. Streaks in a pattern indicate foreign materials inside a nozzle. Remove and clean nozzles; use a soft brush for the tip and screen. Cleaning with a pin, a knife, or any other metallic object can completely change the spray pattern produced by the tip.

Even if you have an accurate pressure gauge, the pressure reading at the gauge usually indicates pressure at the pump not at the nozzle. Always use a second pressure gaugeto check the pressure at the nozzle so you can determine the pressure drop between the pump and the nozzles. There will always be some pressure drop in the supply line, but you should reduce it to minimum. Some factors that cause excessive pressure drop in the system include: a)a sprayer equipped with hoses of the wrong size (the suction hose should always be larger than hoses carrying spray mixture from pump to nozzles), b) supplying tank mixture to one end of the boom; liquid pressure will decrease along the length of the boom (use amanifold to distribute the spray mixture evenly to several boom sections), c) restricting flow by choosing a fitting that has a large inlet orifice but an outlet diameter that is too small.

* Small droplets usually are more efficient in controlling pests because they produce more uniform coverage on the target, and better deposition on the underside of plant leaves. Therefore, nozzles that produce small droplets are preferred when applying insecticides, fungicides, and contact herbicides. However, keep in mind the drift potential of small droplets. They have a tendency to be carried long distances by the wind before depositing. Spray drift should be avoided as much as possible because it results in wasted chemicals and may cause damage to plants, animals, or people adjacent to the sprayed area. Proper selection of application equipment, pesticide formulation, nozzle size and type, and operating pressure and spraying under favorable weather conditions significantly affect the degree of spray drift produced. Avoid spraying when strong winds are present.

* Operate the tractor at a uniform speed to ensure uniform application. There is an inverse relationship between the application rate and the travel speed. For example, doubling the travel speed of a sprayer reduces the application rate by one-half; conversely, halving the travel speed doubles the application rate. Another way to express the influence of travel speed is misapplication rate. A sprayer traveling at 4 km/hr that deviates 1 km/hr would result in a 25% misapplication rate.
Several factors could cause your travel speed to vary. One of the most obvious factors is tire slippage, which may vary from field to field. Therefore, measure sprayer travel speed in the field where you will be spraying. Do not rely on the tachometer or speedometer on the tractor. They are often not accurate enough for your application requirements. A tractor's tachometer is

an excellent instrument for indicating how fast the engine's crankshaft, or rear wheels are turning. But it is not an accurate measure of true ground speed. If, for example, your tachometer ground speed markings were established at a tire pressure of 80 kPa and current tire pressure is only 60 kPa, the tire will now have a smaller rolling radius. Consequently, the tractor will travel at a slower speed than the tachometer indicates. The result will be overapplication of chemicals.

* The only way to determine whether or not a sprayer is actually applying a tank mixutre at the recommended rate is to calibrate the sprayer. The difference between actual sprayer application rate and intended rate should not be more than 5% of the intended rate. Always calibrate the sprayer for application of the exact amount of chemical needed. The flow rate of nozzles, especially those made from brass, increase as they become worn. Therefore, calibrate your sprayer as often as possible.

* Pay attention to uniformity of spray coverage on the target. Spraying the right amount of pesticide on the target is not enough to achieve effective pest control. How uniformly pesticide is deposited on the spray target may be as important as the amount deposited. Each nozzle produces a unique spray pattern. Some nozzles require precise overlapping of patterns from adjacent nozzles. Improper boom height, clogged nozzles, misaligned nozzles spraying at different angles, and using nozzles with different spray angles are some of the most important factors that contribute to non-uniform coverage.

* Maintain the sprayer in good operating condition by periodic inspection and repair. Carry extra nozzles, washers, other spare parts, and tools for quick repairs in the field. Do not run the pump without liquid in the tank.

* Read the sprayer operator's manual and chemical labels to review recommended procedures for safe use of chemicals and the equipment. Wear protective clothing when calibrating, spraying, and cleaning equipment. Goggles, rubber gloves, and respirators or masks are standard equipment when handling pesticides.

Conclusion

Now, more than ever before, applicators need to do a better job of applying pesticides because pesticides used today are more potent and require more precise placement. An applicator has to consider at least the six major factors we discussed previously to achieve best results from a pesticide application. These factors are: 1) know the exact volume of the tank, 2) carefully calculate how much pesticide to add to the tank, 3) measure ground speed, 4) consider the influence of soil type and soil conditions on the amount of pesticide needed, 5) make sure the pressure gauge is working properly, and 6) calibrate the sprayer and make sure the coverage across the field is uniform.

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有效的使用農藥

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摘要

農藥製造商使用大量的時間與金錢去決定農藥的建議用量，建議用量必須大到足以控制田間的目標病蟲害，但又必須儘量的降低以減少使用農民的花費。農藥的使用效率受使用時機、方法與機具的正確與否影響。用藥不足不能控制病蟲害而必須再度施藥而更增加費用；用藥過量費用高，可能產生藥害，並會造成環境污染。農藥容器上的標示是正確的施藥量，但是以這種用量達到防治目的，必須選用正確的噴藥機具、時常校正並正確的操作。

達到滿意用藥的五大影響因素：

1. 正確的識別病蟲害：在你為藥箱裝入農藥前必須確定病蟲害的種類。
2. 選用正確的農藥：要選有效的農藥。
3. 選用正確的施藥機具，特別是能達到用藥目的的噴頭。
4. 正確的施藥時機。
5. 保持噴藥機具的最佳狀況：機具的每一元件都必須定期校正以確定能達到藥瓶標籤的建議用量。

本文將建議能達到最精確有效的液體農藥使用技術。

有效噴藥的準則

完成病蟲害的鑑定與農藥的選用後，下一個步驟是選用適當的施藥機具能夠精確控制用量以達到施藥目的。施藥機具的種類很多，使用者必須依據（1）施藥時期（病蟲害前期、後期、作物是否長出）；（2）目標作物的成長期（幼苗或長成的作物）；以及（3）施藥田區作物的形狀與大小（對土壤或作物施藥，作物形狀：喬木、灌木、草本植物等等）。施藥者所決定的施藥機具種類、機具保養、操作與校正將顯著的影響正確的用藥量。

施藥機具的噴量校正是決定能否正確的依照建議用量施藥的唯一途徑。美國的法規規定農藥施藥量必須在標籤建議用量的 5%以內。但在 Nebraska 州的調查 152 個噴藥的農民與代噴業者，只有四分之一達到 5%以內的預計用藥量 (Rider and Dickey, 1982)。後續的調查指出 103 個接受指導的噴藥者只有 30%達到上述的標準。單次的噴藥作業上有 26%的受指導的噴藥者超量噴藥，每公頃多浪費 3.11 美元(Grisso 等人 1989)。在 South Carolina 州的調查指出約有 85%的施藥者噴藥誤差超過預計用量的 10%以上(Wolak, 1989)。Hofmam 與 Hauck 1983 年指出在 North Dakota 州 60 個經過噴量校正的施藥者有 11 個會超過 10%的誤

差。在 Iowa 與 Ohio 州的噴量校正測試中發現受測者的 20%不能混合農藥達到±5%的預計值(Ozkan 1987)，Montana 與 Colorado 州也有相似的結果。

雖然這只是一小部份地區的調查結果，但數據顯示農藥用量的正確性仍是全美國問題，必須繼續加強施藥者的教育。

農藥能否均勻的分佈在目標上與附著量一樣重要，不均勻附著的原因有噴頭排列不當、阻塞，使用不同噴角的噴頭或噴桿到地面或作物叢的距離改變，這些會造成條狀噴藥、噴藥死角與過度用藥。

以下是有效噴藥程序簡要準則：

*確定施藥機具各重要元件能正確作用，檢查是否會漏。檢查施藥機具是否牢固在承載機具上。

*藥液的混合水要清淨如飲用水，大部份的問題來自水中的雜物，碎屑阻塞濾網，造成噴頭與幫浦的磨損。從池塘或湖泊抽取的水必須過濾。

*各種不同的狀況用藥量不同。例如果園噴藥不同的植株密度建議不一樣的用藥量；土壤用的殺草劑依土壤種類用藥量不同。因此必須閱讀農藥標籤來決定用藥量。

*使用足夠的混合水以確保均勻覆蓋施藥面積。你必須要計算正確的農藥量去調配噴藥液，以符合標籤的指示。亦即你必須能瞭解並依照標籤指示。標籤上的指示用量常為每公頃的使用量，但每個機具的藥箱容量不同，施藥者必須能決定該加入多少藥液，標籤指示會產生混淆，你必須時常驗算。

舉個混合藥液的例子，有個 400 公升的藥箱，若需要的噴藥量為每公頃 40 公升。建議使用量為每公頃 4 公升，則每 40 公升的混合藥液要有 4 公升的農藥。那麼藥箱內該加入多少農藥？這個答案是 40 公升。

*為精確起見，你必須知道藥箱的實際容量。例如標示為 200 公升的藥箱，若稍微過量裝載可以達到 210 公升。在藥箱刻度正確的前提下，上面的例子會造成低於 5%的有效成分。不要太依賴藥箱刻度，精確的量測藥箱容量。藥箱容量可以使用流量計或分別在藥箱空箱與滿載時秤重，再以水的比重換算容量。

*在混合藥液前，必須檢查每一元件。不要忽略任一元件。例如許多施藥者都知道攪拌器的重要性。在大藥箱內，不均勻的攪拌會造成大問題。最嚴重的是使用可濕性粉劑時，藥箱內若有死角或尖銳的角落，不均勻的攪拌會造成藥粉沈積；或是藥粉在均勻混合前長時間的漂浮於水面，噴出的藥液會含有不同濃度的農藥，造成噴藥過量與不足。

*選用能產生適當粒徑、流量與灑佈形狀的噴頭，牢固的鎖定噴頭。

*定期檢視噴頭的噴出形狀，柱狀的噴出形狀表示雜物的阻塞。轉下噴頭並清洗。用軟毛刷清潔濾網與噴嘴，若用針或刀子等金屬物件可能會改變噴嘴與灑佈形狀。

即使你使用正確的壓力錶，錶上的指示是幫浦的壓力，不是噴頭前的壓力。經常檢查噴頭前的壓力，因此你可以知道從幫浦出口到噴頭的壓力降。管路上總是有壓力降，但你必須將它減到最小。下列是幾個造成過度壓力降的原因（1）噴藥機上的軟管尺寸不對（進水軟管必須大於出水軟管）。（2）壓力會從藥箱到噴桿的末端沿途下降（使用分支歧管平均分配藥液到各段噴桿）。（3）使用接頭，一端大另一端小而產生流量的限制。

*細的霧粒通常可以較有效的防治病蟲害，因為可以產生較均勻的附著，並附著在作物的葉背。因此使用殺蟲劑、殺菌劑與接觸性殺草劑，適合使用較細的霧粒。但是必須注意細的霧粒可能產生的飄積，它們在附著前會被風攜行很長的距離。噴霧的飄積必須盡量避免，因為會造成藥劑的浪費並可能對作物，人畜產生危害。適當的選用噴藥機具、藥劑配方、噴頭大小與形式、作業壓力，以及在合適的天候條件下噴藥可以減少飄積的產生。避免在強風下噴藥。

*以均勻的速度駕駛曳引機以確保均勻噴藥。施藥量與車行速度成反比。若車行速度加倍，施藥量將減半；反之，車行速度減半，施藥量將加倍。用另一種方法表示車行速度對施藥誤差率的影響，若一噴藥車以 4 **km/hr** 的車速前進，每 1 **km/hr** 的速度誤差，產生 25%的施藥誤差。

有許多造成車行速度的變異，但最大的原因是車胎在不同田區產生不一樣的打滑。因此在你要施藥的田區測定噴藥速度，不要依據曳引機上的轉速計或速度錶，在此用途上它們常不夠精細。引擎轉速計可以正確指示曲柄軸或後輪的轉速，但並不能正確量測車行速度。例如你車上的速度錶是依據胎壓 80 **kPa** 計算的，現在你的胎壓只有 60 **kPa**，輪胎半徑較小，造成車行速度比車速錶速度小，如此會過度施藥。

*唯一能知道藥箱內的混合藥液液是否符合建議量的途徑是噴量校正。實際施藥量與建議使用量的誤差不得超過 5%。要經常作噴量校正以正確施用藥劑。黃銅噴頭磨耗時噴量會增加，因此必須經常作噴量校正。

*注意附著均勻度，只將足夠的藥量噴向作物是不足以達到有效的病蟲害防治。農藥的附著均勻度與使用量一樣重要。每一噴頭必須產生均勻的灑佈形式，有些噴頭必須與鄰近噴頭有適當的覆蓋重疊。不正確的噴桿高度，阻塞的噴頭，不正確的角度排列，混用不同噴角的噴頭等等是造成不均勻附著的原因。

*定期檢查維護噴藥機具，以保持良好的作業狀況。田間作業時攜帶備用噴頭、墊圈、備品以及工具。不可在空藥箱時開動幫浦。

*詳讀噴藥機具的使用者手冊與農藥標籤，檢查機具與農藥的正確使用程序已確保安全。作噴量校正、施藥、清潔機具時穿著防護衣。處理農藥時護目鏡、

橡皮手套、口罩或防毒面具是標準的裝備。

結論

現在使用的農藥更具危險性，必須小心使用，施藥者施藥時必須更用心。施藥者至少必須考慮上文所述的六個準則。即（1）藥箱的正確容量；（2）正確計算加入藥箱的農藥量；（3）量測車行速度；（4）考慮土壤種類與狀況決定農藥用量；（5）確定壓力計功能正常；以及（6）作噴量校正確保田間均勻覆蓋。

Reducing Pesticide Waste

H. Erdal Ozkan   Robert D. Fox[1]

Introduction

Pesticide use in the United States increased from 200,000 pounds per year in the 1950s to more than 1 billion pounds per year by 1987. The dramatic increase in pesticide use creates difficulties in safe and proper disposal of pesticide-related wastes. Pesticides are largely responsible for the abundant and high-quality food supply in the United States. However, if handled or applied improperly they may harm the environment or lead to contamination of surface and ground water resources.

Recent studies indicate that improper handling and disposal of pesticide waste are responsible for most contamination cases. Pesticide waste results from unused pesticide products, excess spray mixture, unrinsed containers, and rinse water from containers and equipment. The best strategy for dealing with waste is to eliminate the source of the waste. However, any reduction in pesticide waste will help protect water resources from pesticide contamination. Substantial reductions in pesticide waste can be accomplished legally, responsibly, and economically.

Listed below are recommendations for reducing pesticide waste, including information on the most common causes of excessive waste.

1. Follow IPM Practices

The first step in reducing pesticide waste is to determine how much pest damage can be allowed before pesticide use is warranted. Examine alternative control practices before purchasing pesticides. The need for pesticides, and, consequently, the risk of surface and ground water contamination, can be reduced through Integrated Pest Management (IPM) practices such as scouting, crop rotation, fallowing, planting resistant cultivars, alternating pest control products, and considering economic thresholds. Many row-crop growers are reexamining the costs and benefits of mechanical cultivation for controlling weeds. Studies indicate that a combination of mechanical cultivation and banding herbicides provides adequate weed control while greatly reducing pesticide use.

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2. Purchase Only What You Need

Avoid problems with unused products (undiluted pesticide concentrate) by checking your storage area each year before purchasing chemicals. Buy only the amount of pesticide you will use in one growing season. Store unused pesticides properly for use the following season.

3. Improve Application Accuracy

Check the accuracy of your sprayer periodically to make sure you are applying the amount recommended on the pesticide label. Guidelines established by the U.S Department of Agriculture and the Environmental Protection Agency indicate that the difference between a sprayers actual application rate and intended application rate should not exceed 5 percent of the intended rate. However, surveys conducted in various locations in the USA indicate that only one out of four sprayers are applying chemicals with application errors less than 5 percent.

4. Eliminate Leftover Spray Mixture

Avoid leftover diluted pesticide in your spray tank following a pesticide application. A few simple calculations can be used to determine the amount of spray mixture needed to spray a field of a known size. Follow these steps to determine the amount of water and pesticide concentrate you need to add to the tank:

1. Determine the area to be sprayed (hectares, square meter etc.)
2. Multiply this area by the application rate of the sprayer to find the amount of spray mixture needed in gallons.
3. Multiply the area to be treated by the pesticide rate to determine the amount of pesticide you must add to the tank.

Example

A sprayer has been calibrated to apply 60 liters of spray mixture per hectare. The pesticide label recommends 2 liters of commercial product per hectare for broadcast application. Determine how much water and pesticide must be added to cover 10 hectares.

Spray Mixture Needed = Spray Output (Liter/Ha) x Hectares to be Sprayed

= 60 L/ha x 10 hectares = 600 liters of spray mixture needed

Amount of Pesticide Needed = 10 hectares x 2 L/ha = 20 Liters

So, if the total solution should be 600 liters, the final mixture should contain 580 liters water and 20 liters of pesticide formulation.

5. Rinse Containers Immediately

Concentrated pesticide residues leaking from unrinsed, discarded containers can cause significant environmental contamination. Up to 0.1 liter of pesticide may be left inside a 20 liter container after normal emptying. Depending on product cost, proper container rinsing could save significant money in pesticide cost alone. Containers should be rinsed immediately after they are emptied because dried residue is difficult to remove.

Triple rinsing is the most common procedure for rinsing containers. It involves filling each container at least one-quarter full with water, replacing the lid, shaking the container, and then emptying the liquid from the container into the spray tank. This is done three times with each container. A new approach, pressure rinsing, allows containers to be rinsed while pesticides are emptied into the spray tank. Special nozzles attached to a garden hose are used to puncture plastic and metal containers. When turned on, the nozzle produces a forceful spray inside the empty container. By holding the container over the opening of the spray tank or holding tank while rinsing, the rinse water can be captured as it drains from the container spout. It takes a few minutes to properly triple rinse a container, but less than a minute to pressure rinse. The amount of rinsate generated is also reduced with the pressure-rinsing method.

6. Reduce Rinsate

Spray equipment requires periodic cleaning and rinsing to keep vital components in good working condition and when changing from one pesticide to another. Improper management of rinsate has great potential for contaminating surface and ground water. The best way to eliminate this problem is to perform all interior and exterior rinsing in the field immediately following the application. Equipment may also be rinsed at a modern pesticide mixing and loading facility equipped with a concrete rinse pad and rinsate-collection pit. However, disposal of the rinsate collected in the pit could become a major problem. This is why it is important to reduce the amount of rinsate to a minimum.

If possible, reuse the rinsate when preparing the next batch of tank mixture. Make sure all the dirt and debris in the rinsate are filtered out before adding the rinsate to the spray tank. The small amount of solids left in the collection pit should be dried and taken to a hazardous waste disposal site or spread evenly over a large part of the field.

7. Modify Spraying Equipment

Take advantage of technological advancements in pesticide application equipment design, and modify your equipment to improve application efficiency while reducing pesticide waste.

Recent developments in pesticide application equipment allow for safer operation and less risk to the applicator and the environment. For example, sprayers with in-line pesticide-injection systems eliminate leftover tank mixtures. With these systems, the

pesticide and water are kept in separate tanks. A separate metering pump feeds the pesticide into the spray line. Any excess water is left in the water tank, and excess pesticide remains in the pesticide tank.

Many new sprayers are equipped with a small tank that holds clean water to rinse out the sprayer tank in the field. Immediately following the application, clean water can be pumped into the large spray tank, and the rinse water can be sprayed over the target field, provided registered rates are not exceeded and application is consistent with label directions.

Research is under way to develop new equipment and methods that will further improve application efficiency. For example, researchers are developing systems that automatically adjust pesticide rates according to the amount of organic matter in the soil. This system operates on the principle that lighter soils, which are low in organic matter, require less pesticide than darker soils.

Some studies indicate that ultra-low volume (ULV) pesticide applications using electrostatic nozzles provide satisfactory insect control at half the rate recommended for conventional spraying. Such techniques mean greater pesticide efficiency and less pesticide consumption, which results in reduced pesticide waste.

8. Choose Pesticides Packaged In Returnable/Refillable Containers

Many agricultural chemical companies have developed new pesticide packaging to protect users from exposure and reduce pesticide waste. For example, minibulk containers, ranging in volume from about 40 to 600 gallons, have become increasingly popular over the last few years. Minibulk containers reduce the number of small containers, which are major sources of pollution. Minibulk tanks usually are returned to the dealer for refilling or for deposit. Nearly every major company offers a minibulk for one or more of its products.

While some companies are promoting small-volume returnable containers, others are trying to eliminate the container altogether. One company has pressed dry pesticide into an effervescent tablet that can be broken into small parts for reduced applications or used whole at full strength for normal applications. Another company is packaging pesticides in small water-soluble pouches that improve safety in normal handling and eliminate problems with container rinsing and disposal.

Some equipment manufacturers and agricultural chemical companies are joining forces to reduce pesticide waste and improve applicator safety. Returnable chemical containers are being designed to fit directly into a valve on the lid of a planter's pesticide hopper. This reduces the risk of the applicator inhaling pesticide dust, which is a recurrent problem with conventional dry granular pesticide packaging.

Summary

Pesticides are likely to remain the primary means for controlling pests for many years. They play an important role in producing the abundant high-quality food we all enjoy. However, improper handling, application, or disposal of pesticides poses substantial danger to human health and the environment. There is no practical and cost-effective way to dispose of pesticides. Although pesticides are considered hazardous wastes and should be disposed of at hazardous waste disposal sites, this type of disposal is not a long-term solution. The best strategy for dealing with any waste is elimination. Hence, any reduction in pesticide waste is a positive step toward protecting the environment from contamination. This publication presents several practices that will help reduce or eliminate pesticide waste.

農藥廢棄物減量

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前言

美國的農藥使用量從 1950 年代的每年二十萬磅，升高至 1987 年的每年超過十億磅。農藥使用的急遽增加產生農藥相關廢棄物的安全與棄置難題。美國食糧的增產與品質的提高，主要仰賴農藥的使用；但是農藥的不正當使用會造成環境的危害，地表水與地下水的污染。

最近的研究指出不當的處理或棄置廢棄農藥是造成許多污染的原因。農藥廢棄物主要來自未使用的農藥、剩餘的混合藥液、未清洗的容器以及清洗容器與機具的清洗廢水。減廢是處理廢棄物的最佳策略，減少農藥廢棄物不論多少都有助於減少農藥污染，並且大量的減廢可以靠立法、責任與經濟利益來達成。

下列所述為包括產生過量農藥廢棄物的原因與減少農藥廢棄物的建議：

1. 遵照病蟲害綜合防治方法(IPM)

農藥廢棄物減量的第一步是決定對病蟲害的不使用農藥的容忍程度。購買農藥前先考慮其他的防治方法。農藥的需要量與其所將產生的地表與地下水污染可以靠綜合防治法減少。綜合防治法有如摘除、輪作、休耕、種植抗病蟲品種、更換病蟲害防治藥物以及考慮經濟的容忍度。許多以條栽種植作物的農民已重新評估機械除草的費用與利益，研究指出使用機械除草與除草劑的帶狀灑佈可以控制雜草並大量降低農藥使用量。

2. 只購買你所需的量

每年購買農藥之前檢查你的農藥貯藏室，以避免堆積未使用農藥的問題。購買本期作物所需的農藥；妥善貯存未使用農藥供下期使用。

3. 改善施藥精度

定期檢查施藥精度確保依據農藥標籤建議的使用量。依據美國農業部與環保署的準則，施藥量與建議量的差異應在 5%以內。但在美國各地的調查顯示只有四分之一符合此要求。

4. 避免剩餘混合液

避免在噴灑農藥後你的藥箱還有農藥。幾個簡單的計算就可以算出你要施

藥面積所需的混合藥量。下列是你所需要的計算步驟：

（1） 決定你要施藥的面積（公頃、平方公尺等）

（2） 將面積乘以施藥量而得到混合藥液的容量。

（3） 將面積乘以農藥使用量以決定你必須加多少農藥於藥箱內。

例題：

一施藥機經噴量校正得知每公頃的噴霧量為 60 公升。農藥標籤建議使用量為每公頃 2 公升。若要防治 10 公頃的田地必須使用多少農藥和水？

混合藥液需要量=噴霧量（公升/公畝）x 施藥公頃數

=60 公升/公頃 x10 公頃=600 公升噴霧量

農藥需要量=2 公升/公頃 x10 公頃=20 公升農藥

因此你所需要的混合藥液有 600 公升，混合液中有 580 公升的水和 20 公升農藥。

5. 迅速清洗農藥包裝容器

從未清洗丟棄的農藥包裝容器流出的農藥會嚴重的造成環境污染。使用過的20公升農藥包裝容器可能會有高達0.1公升的農藥殘留。假使是昂貴的農藥，適當的清洗可以節省一筆錢。農藥包裝容器在農藥倒出後要迅速清洗，若讓殘留部份乾了就不容易清除。

三段清洗是清洗容器常用的方法。首先將空容器注入四分之一容量的清水，蓋上蓋子搖盪，然後將液體倒到藥箱。每一個容器重複這個步驟三次。有一個新的方法是噴水清洗，將特殊的噴頭裝在澆花的水管上，用來清洗塑膠與金屬的農藥包裝容器。將容器倒拿在藥箱的開口上，開啟水龍頭，清洗水流出時可以流入藥箱。用三段清洗法約要幾分鐘，但噴水清洗法只需要佈道一分鐘。噴水清洗產生的清洗廢水也較少。

6. 減少清洗廢水

施藥機具需要定期清洗以使各重要零件保持最佳狀況，在換噴不同農藥時也一樣需要清洗。不當的處理清洗廢水會造成地表水與地下水的污染。最佳的處理途徑是在施藥後立即在田區作施藥機具內、外部的清洗清洗。有一種新型的農藥混合與裝載設備附有水泥的清洗槽和清洗廢水的收集坑，但是坑內的清洗廢水的棄置仍是一個問題，所以仍必須將清洗廢水減到最少。

有一種可能是在下一次備製農藥混合藥液時使用上一次的清洗廢水，但必須在倒入藥箱時確實的將殘渣與泥沙過濾。廢水收集坑內殘留的固體必須經過乾燥後拿到有害廢棄物掩埋場或均勻的分灑在大面積的田區內。

7. 改良施藥機具

由於先進科技的助力而有新設計的施藥機具可以改良施藥設備的施藥效率並減少農藥廢棄物。新型的施藥機具可以減少對施藥者與環境的危害。例如線上注入系統可以避免藥箱的殘留。這種系統將農藥與水分開裝在兩個箱內，由一個定量幫浦將農藥注入噴藥的管路。所有的剩餘水留在水箱；所有的農藥留在農藥箱。有一些新的施藥機具附有小清洗水箱，以便在施藥後在田區立即清洗機具。清洗水可以打入藥箱清洗，清洗廢水可以噴入田區，只要不會超過註冊量或符合農藥標籤指示。

有一些新型施藥機具與方法的研究可以使施藥效率更改進。例如有人研究依照土土壤中有機物的多少自動調節施藥量。其原理是含有機物的土壤反射光弱，因此顏色深的土壤需要較少的農藥。

有些研究指出已加靜電噴頭噴灑超低容量農藥來防治蟲害，可以使用比傳統方法減半的農藥，這種方法可以提高施藥效率，降低農藥用量，而減少農藥廢棄物。

8. 選購裝在可回收或可重複使用容器的農藥

有些農藥廠商已發展出保護使用者免於暴露於農藥廢棄物的包裝。例如近幾年漸漸流行 40 到 600 加侖的大容量包裝。大容量包裝減少主要污染源的小包裝容器。大包裝可以拿到農藥店再裝或棄置。幾乎每一個農藥廠商現在都有一兩種使用大包裝的產品。

有些廠商則促銷可回收的小包裝容器，但有些廠商則在消除包裝容器。有一家廠商將農藥製成發泡錠劑，一般用量可以使用整個藥錠，減量使用時可以破開使用。另一家則將農藥裝在小的水溶性包裝袋，這樣可以改善輸送的安全又可以解除清洗與棄置的問題。

有些農機廠商和農藥廠商合作來提高施藥效率與減少農藥廢棄物。可回收的包裝容器可以直接接上播種機農藥箱蓋子，將農藥倒入。如此可以降低施藥者吸入農藥粉塵的危險，這樣消除使用乾粉粒劑型農藥的危險。

摘要

農藥在生產大量我們喜歡的高品質食品時佔重要的地位，在近年內仍是控制病蟲害的主要方法。但是不當的處理、施用或棄置農藥會造成人體與環境的嚴重危險。現在仍沒有一個實用與廉價的方法棄置農藥廢棄物。農藥被視為有

害的廢棄物，必須棄置在有害廢棄物掩埋場，這並不是長久之計。減廢是處理廢棄物的最佳策略。因此任何減少農藥廢棄物對保護環境都是正面的。本文提出許多幫你減少農藥廢棄物的實用方法。

CALIBRATION OF SPRAYING EQUIPMENT

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Calibration refers to **all** the operations that ensure the correct amount of pesticide will be applied to the treated area. These operations include: 1) calculating the amount of product, 2) mixing properly and safely, 3) adjusting equipment to deliver the desired rate uniformly across the spray swath, 4) determining effective swath/overlap, 5) checking accuracy during operation, and 6) detecting and correcting errors.

Application equipment must be calibrated periodically to achieve effective pest control and to reduce the potential for excessive pesticide residues remaining on sprayed surfaces. While applying too little pesticide may result in ineffective pest control, too much pesticide wastes money, may damage the crop and increases the potential risk of contaminating ground water and environment.

A survey of 53 private and municipal golf course pesticide applicators in Nebraska revealed that only one of six applicators applied pesticide carrier volumes within the acceptable error margin of ± 5 percent. Application errors ranged from 83 percent under application to 177 percent overapplication. Thirty-six percent of the applicators over applied pesticides by more than 5 percent of their intended application rate. The applicators overapplied pesticides by an average of 19 percent. The cost of overapplication for group using Daconil 2787 ranged from 12 cents per hectare to $16 per hectare. Faulty pressure gauges and improperly sized hoses and plumbing components were contributing factors to inaccurate tank-mix application rates and non-uniform applications. Varner et al. (1990).

A survey of 152 private and commercial applicators in Nebraska revealed that only one out of four farmers were applying pesticides within 5% of their intended application rate (Rider and Dickey, 1982). A follow-up field survey of 103 private pesticide applicators in Nebraska indicated that only 30% of the cooperators were applying herbicides within 5% of their intended application rate (Grisso et al., 1989). Twenty-six percent of the cooperators overapplied herbicides during a single application, with an average cost due to misapplication of $3.11/ha.

A survey conducted in South Carolina indicated that nearly 85% of applicators applied pesticides with errors greater than 10% when compared to intended rates (Wolak, 1989). Hofman and Hauck (1983) reported that only 11 of the 60 sprayers they calibrated in North Dakota were applying chemicals as the operator predicted. Calibration clinics conducted in Iowa and Ohio revealed that only 20 percent of sprayers calibrated were capable of applying a tank-mix within ± 5% of the intended application rate (Ozkan, 1987). Similar findings were reported from calibration clinics conducted in Montana and Colorado. This limited data indicates that in general, pesticide application accuracy continues to be a problem regardless of the geographic location. This problem, however, can be reduced to minimum with proper and frequent calibration of sprayers.

Sprayers should be calibrated several times a year. Changes in operating conditions and the type of chemical used require a new calibration. Frequent calibration is even more important with liquid application because nozzles wear out with use, increasing the flow rate. For example, tests conducted by Reichard et al. (1991) indicated that the flow rate of 0.8 liter-per-minute capacity brass nozzle increased by 10 percent after only three hours of use with a wettable powder material.

The results of the survey conducted by Varner et al.(1990) indicated a positive correlation between application accuracy and the frequency of calibration. Approximately 67 percent of the operators who calibrated before every spray operation had application errors below 5 percent while only 5 percent of those operators who calibrated their equipment less than once a year (once every two, three, four years) achieved the same degree of application accuracy.

A. Calibrating Liquid Application Equipment: Although there are many methods used to calibrate liquid application equipment, the methods described here are the most common. Choose a method that you are most comfortable with.

For safety, use water instead of actual chemical mixtures when calibrating. However, some carriers, such as liquid fertilizers, are much denser than water and may cause the nozzle flow rate to vary from the rate obtained with water. In this case, determine the average nozzle output with water and use a conversion factor that is usually listed in the nozzle manufacturer's catalog.

To calibrate a sprayer, you need a measuring tape, a stop watch or an ordinary watch with a second hand, and a measuring jar graduated in milliliters. A pocket calculator also will be handy. Regardless of the type of liquid application equipment you are calibrating, the calibration procedure requires checking the nozzle flow rate and the actual travel speed of the sprayer. Although the procedure is similar, steps involved in calibrating boom-type, manual backpack and hand gun sprayer are presented separately below.

Follow these steps when **calibrating low-pressure boom sprayers**.

Step 1. Fill the sprayer tank with water.

Step 2. Run the sprayer, inspect it for leaks and make sure all vital parts function properly.

Step 3. Determine the spray width per nozzle **(W)** in meters.

For broadcast application, W= Nozzle spacing

For band spraying, W= Band width

For directed spraying, $W = \dfrac{\text{Row spacing (or band width)}}{\text{Number of nozzles per row (or band)}}$

Step 4. Determine Travel Speed **(km/h)**.

To determine the travel speed, measure a known distance Use fence posts or flags to identify this distance. A distance over 50 m and a tank at least half full are recommended. Travel the

distance determined at your normal spraying speed and record the lapsed time in seconds. Repeat this step and take the average of the two measurements. Use the following equation to determine the travel speed in km/h:

$$\text{Travel Speed (km/h)} = \frac{\text{Distance (m)} \times 1000}{\text{Time(seconds)} \times 60}$$

Step 5. Determine Nozzle Flow Rate (L/min)

With the sprayer parked, run the sprayer at the same pressure level and catch the output from each nozzle in a measuring jar for one minute (or collect output for half a minute and then double the amount collected) to determine the nozzle flow rate in liters per minute. Check for clogs and clean the tip or replace any nozzle tips having flow rates 10 percent more or less than the average of the other nozzles checked, and/or having obviously different fan angles or patterns. Repeat the above process until the variation in discharge rate for all nozzles is within 10 percent of the average.

Step 6. Determine the Actual Application Rate (L/ha) using the following equation:

$$\text{L/ha} = \frac{\text{L/min} \times 600}{\text{(km/h)} \times W}$$

L/min: average nozzle flow rate in liters per minute
km/h: travel speed in kilometers per hour
W: effective spray width per nozzle in meters (as determined above)
600: constant to convert units to liters/hectare

Step 7. Compare the Actual Application Rate with the Recommended or Intended Rate

If the actual rate is more than 5 percent higher or lower than the recommended or intended rate, you must make adjustments in either the pressure or the travel speed or in both. If these changes don't bring the application rate to the desired range, then you may have to select a new set of nozzles with smaller or larger openings. (Refer to "Useful Formulas" to determine the new travel speed and/or the pressure rate.

Step 8. Recalibrate the Sprayer

Repeat steps 5 through 7 above until the application error is within 5 percent of the intended application rate.

The principles for **calibrating manual hand can and backpack sprayers** are essentially the same as those for boom sprayers outlined previously. Here are the steps involved in the calibration process:

Step 1. Measure and mark off an area equal to 100 square meter (such as 10 m x 10 m).

Step 2. Add a measured amount of water to the tank, spray the area and then measure the amount of water remaining in the tank. The difference between the amount in the tank before and after spraying is the amount used per 100 square meter.

Step 3. Compare the measured rate with the intended or recommended rate. If the difference is greater than $\pm 5\%$ of the intended rate, make necessary adjustments and recalibrate the sprayer.

An alternative method is to record the time required to spray 100 square meter and later catch and measure the spray from the nozzle (or nozzles) used for the same time period.

Calibrating a hand gun nozzle is similar to calibrating a backpack sprayer. Spray a known area and record the time required to cover this area. Then use a bucket to catch the spray from the hand gun for the time period elapsed during spraying of the marked area. Determine the application rate by measuring the amount of liquid in the bucket.

B. Calibration of Granular Herbicide Application Equipment: Herbicide labels list the rate at which the product should be applied. Some labels will also list the correct setting for some name-brand spreaders. However, these settings are just recommendations to provide a good reference point when calibrating spreaders. Seldom does a setting give the same application rate in all operating conditions and application sites. Variables such as particle size, particle density, particle shape, relative humidity, drop point of granules on the impeller plate, impeller speed and ground speed all affect the application rate and the distribution pattern. Therefore, granular applicators should be calibrated for each type of granular product being applied and for change in operator, weather and field conditions.

Before beginning to calibrate a granular applicator, be sure that it is clean and all parts are working properly. Always wear rubber gloves and other protective clothing to prevent contact with chemicals during cleaning and calibration of equipment and actual application of chemicals.

The primary purpose of calibration is to determine the actual delivery rate of a spreader regardless of its type. However, with rotary spreaders, it is also necessary to check and correct the distribution pattern.

"Delivery rate" refers to the average amount of product applied over a known area, and it usually is expressed in kg/ha or kg per 1,000 square feet. The easiest way for an operator to check the actual output rate is to collect and weigh the granules actually applied to a known area. You can do this by following one of the two methods explained below. Both methods are acceptable, but the first one produces a more precise calibration.

Method I

a) Spread out a plastic tarp of known size on the ground.

b) Operate the spreader at a known speed across the tarp.

c) Determine the area covered. If the swath width is wider than the tarp, the area covered is equal to the area of the tarp. If the swath is narrower than the tarp, multiply the swath width by the tarp length to determine the area covered. It is highly recommended you keep the tarp width wider than the swath width for a more accurate measurement of the delivery.

d) Place all the granules on the tarp into a container and weigh them.

e) Divide the weight of granules collected by the area covered to determine the actual delivery rate in grams per square meter.

f) Compare the measured (actual) delivery rate with the rate recommended on the label. Make proper adjustments and recalibrate the spreader until you reach the desired accuracy (a variation within ± 5 percent of the label recommendation is acceptable).

Method II

The second method is not as precise as the first one, but it is preferred by many operators because it does not require a tarp. However, the principle is the same. For calibrating, this area should be at least 50 m^2 for drop spreaders and 100 m^2 for rotary spreaders. Once you set up the known area that will be covered, follow the steps below to complete calibration.

1. Fill the spreader to a known level marked on the inside of the hopper.
2. Operate the spreader over the known area already set up.
3. Weigh the amount of material needed to refill the spreader to the mark. Record the weight in grams.
4. Grams of product actually applied per square meter can be calculated as follows:

$$\frac{\text{Amount needed to refill (grams)}}{\text{Area covered (sq. meter)}} = \text{Product applied (g/m}^2\text{)}$$

Drop-type spreaders provide fairly uniform **distribution of granules** across the swath width. The distribution is not affected much by product physical characteristics, weather conditions, etc. However, rotary spreaders are very sensitive to these variables, and patterns can be severely skewed if these variables are neglected. Therefore, always check the distribution pattern of granules when using rotary spreaders.

The best method to check the distribution pattern is to lay out a row of shallow cardboard boxes on a line perpendicular to the direction of travel (Figure 30). Boxes with partitions will prevent chemical particles from rebounding. All boxes should have the same area and height (0.20 m^2 area, 3 to 5 cm tall). Space the boxes 30 cm apart, and make sure the row is 1.5 to 2 times the width of the anticipated effective swath.

To conduct the test, fill the spreader at least half full, set it at the label setting for rate and pattern, and make three passes in the **same** direction over the boxes. Be sure to turn the spreader on and obtain proper travel speed before crossing the boxes.

Put the material for each box into a test tube, vial or small narrow bottle. When the bottles are placed side by side in order, a plot of the pattern is visible. The effective swath width is twice the distance out from the center of the spreader to the point where the rate is one-half the average rate at the center of the pattern. For example, if the first three to four bottles for the center have material 4 cm deep and the bottles from the 3-meter positions (3 m left of the spreader centerline or 3 m right of the centerline) have material 2 cm deep, the effective swath width is 6 m. Therefore, you should be making passes 6 m apart to provide a uniform coverage throughout the area covered.

In some cases, a rotary spreader's distribution pattern may not be uniform enough, even after all spreader adjustments have been made. A common recommendation in such cases has been to cut the rate of application in half to cover the field twice at right angles. However, research conducted by Parish (1986) revealed that cutting the rate in half and cutting the swath width in half while maintaining parallel swaths is more effective than the "right angle" method. The "half width" method is practical mainly for correcting severe pattern problems that remain after all mechanical adjustments to the spreader have been made.

There is always the question of which of the two modes of spreader operation -- continuous, back-and-forth mode or the circuitous, round-and-round mode -- gives a more uniform spreader distribution. Parish (1988) analyzed the distribution pattern data from 90 spreader test runs involving four spreaders with several products and pattern settings. They found that when the continuous spreader pattern is generally acceptable, there is statistically no advantage to using the more cumbersome circular mode of operation. However, if the basic spreader pattern remains badly skewed after all the spreader adjustments are made, the circular mode may help improve the overlapping pattern. However, the half-rate, half-width method with the continuous mode is probably more effective in such cases. It is also easier to use and requires little additional travel over the turf area.

Mixing and Loading Chemicals

Mixing the pesticide thoroughly and carefully is an important step in good sprayer operation. Incomplete mixing results in varied application rates--too high at times, too low otherwise. Some chemicals, when mixed improperly with others, form a thick, mayonnaise-like mixture that will not spray properly and is difficult to clean out of the sprayer. Always read the label for proper mixing sequence, and test the compatibility of chemicals in a small container before mixing.

Generally, when preparing the spray mixture, fill the tank half full of water and pour in the correct amount of chemical while the pump is running. Then finish filling the tank. When using wettable powders, again fill the tank half full, make a slurry in a separate container or through an inductor system, and then add the slurry to the tank to ensure good mixing. Rinse the slurry container three times, pouring the rinsate into the tank. Finally, finish filling the tank with water.

You can spend hours in the field calibrating your sprayer to achieve the desired accuracy, but your efforts are wasted if you don't know how much chemical to put in the tank. In a survey conducted by Rider and Dickey (1982), 38 percent of the applicators failed to add the correct amount (within ± 5% of the required amount)

of chemical to the tank. In South Carolina, 76% of the applicators surveyed had tank-mix errors greater than 10% (Wolak, 1989).

The amount of chemical needed per tankful depends on the recommended rate and the size of area you can treat per tank of spray. Calculations are the same whether you are using a manual backpack sprayer or a powered boom sprayer. Assuming that a boom sprayer is to be used, the steps involved in determining the right amount of pesticide to add to the tank are: 1) Determine the area (hectares) to be treated per tank. To determine this, divide the tank capacity by the L/ha application rate. 2) Next, find the amount of pesticide needed per tank by multiplying the number of hectares treated per tank with the amount of actual chemical to be applied per hectare.

Sometimes, chemical manufacturers give recommended rates in terms of active ingredient (A.I.) to be used per acre rather than the amount of total product per acre. In these cases, calculate the amount of material to be applied as shown in examples 2 and 3 for dry chemicals and liquid chemicals, respectively.

USEFUL FORMULAS

* **To determine travel speed**

$$\text{Travel speed (km/h)} = \frac{\text{Distance (m)} \times 1000}{\text{Time (sec)} \times 60}$$

* **To calculate the resulting application rate (L/ha) for any change in travel speed (km/h):**

$$(L/ha)_2 = \frac{(L/ha)_1 \times (km/h)_1}{(km/h)_2}$$

* **To determine the desired travel speed (km/h) when changing application rate (L/ha):**

$$(km/h)_2 = \frac{(L/ha)_1 \times (km/h)_1}{(L/ha)_2}$$

* **To determine the resulting application rate (L/ha) when changing nozzle pressure:**

$$(L/ha)_2 = (L/ha)_1 \times \text{SQRT} \{ kPa_2 / kPa_1 \}$$

* **To determine the desired pressure (kPa) that will produce a desired application rate (L/ha):**

$$kPa_2 = kPa_1 \times \{ (L/ha)_2 / (L/ha)_1 \}^2$$

* **To determine the resulting nozzle flow rate (L/min) when changing nozzle pressure**

$$(L/min)_2 = (L/min)_1 \times SQRT\{ kPa_2 / kPa_1 \}$$

$(L/ha)_2$, $(L/ha)_1$: Desired and measured application rates, respectively
$(km/h)_2$, $(km/h)_1$:Desired and measured travel speeds, respectively
kPa_2, kPa_1 :Desired and measured spraying pressures, respectively
$(L/min)_2$, $(L/min)_1$: Desired and measured nozzle flow rates, respectively

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噴霧機具之檢校

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校正之工作在確保在噴藥區施給正確噴藥量，其工作項目包括（1）計算作物量（2）適當安全的混合工作（3）調整設備使植行獲得均勻噴灑適當農藥（4）決定有效重疊噴灑面積（5）檢查作業精度（6）檢知並校正誤差。

美國內布拉斯加州只有 25%的農民能準確控制噴藥量誤差在 5%的範圍以內。代耕中心過量噴施農藥約佔 26%，每公頃約增加美金 3.11 元經費。在俄亥俄州檢定過的噴藥機中只有 20%能控制噴施量誤差於±5%以內。經常確實校正噴藥量亦可確保準確施藥量。每年必須做多次檢校工作，作業條件或噴嘴及農藥種類改變時即須做檢校工作。

A. 桿式液態噴藥機之檢校

用清水做檢校工作，再乘以適當係數以轉換成藥劑流量。所需工具為量尺、馬錶或手錶，量筒。檢校步驟如下：

1.將藥筒充滿清水。

2.試噴檢查各機件是否正常。

3.依據噴施方式測定每個噴頭噴灑寬度 W（公尺）。

撒噴式，W＝噴頭距離

帶式，　W＝施藥帶寬度

直噴式，$W = \dfrac{\text{行距(或帶寬)}}{\text{每行(帶)噴頭個數}}$

4.量測噴藥車車速（公里/小時）。

量測時，距離至少五十公尺，藥桶半滿以上。

5.量測噴藥頭流量（公升/分）。

在相同壓力下將量杯放置於噴頭下方收集並記錄排液量，每個噴頭流量與平均流量的差距必須在 10%以內。若不符合要求必須換新噴頭或排除阻塞物後再重複量測之。

6.計算實際噴藥量。

$$\text{公升/公頃} = \frac{\text{公升/分} \times 600}{\text{公里/小時} \times \text{W(小時)}}$$

7.比較量測值與期望施用量。

兩者相差 5%以上時必須調整壓力或車速，或更換新噴頭。

8.重複步驟五到步驟七，直到與期望施用量的誤差在 5%以下。

手提示與背負式噴藥機的檢校方法略似上法。

B. 粉粒狀農藥撒佈機之檢校

<u>混合與裝填農藥</u>

依照指示與步驟來混合不同農藥以免產生質變阻塞噴頭或增加清洗難度。

一般在商品上會標示農藥撒佈參考量。粉粒農藥的顆粒大小、密度、形狀、相對濕度，農藥在撒佈翼上的落點位置，撒佈翼迴轉速和車速等因子都會影響藥量及撒佈情形。因之，粉粒農藥、駕駛人、氣候與田間條件改變時都必須做檢校工作。

檢校之前應確認所有機件之保持潔淨且運轉正常，檢校時必須穿戴橡膠手套和防護衣物，避免直接接觸農藥。以下為檢校步驟。

1.於地面上鋪設防水塑膠帆布。帆布寬度必須大於植行寬度。

2.以固定速度在帆布上操作撒佈機。

3.量測覆蓋面積。

4.收集帆布上所有粉粒農藥並加以秤重。

5.計算每平方公尺農藥撒佈量。

6.撒佈量與標示撒佈量差異要在±5%以內，否則應調整機具再重複檢校工作。

另一方法為首先裝滿藥桶，在撒佈於一固定面積之後，再填滿藥桶，將填入之農藥量除以面積即得到每單位面積農藥撒佈量。

一般而言，直接落下式的撒佈機之農藥分佈甚為均勻。而迴轉式撒佈機田間農藥分佈受到粉粒農藥物性、氣候等條件的影響，因之必須經常檢測農藥分佈狀況。檢測粒狀農藥分佈的方法可在田間植行兩側放置一排或多排間距 30 公分的紙盒（面積 $0.2m^2$，高 3~5cm），擺放紙盒的寬度須為預定撒佈寬度的 1.5~2 倍。各個紙盒內需裝有小隔板以防止粉粒農藥跳動掉出盒外。

檢測時，將藥箱裝半滿農藥，在同方向以正常速度撒佈農藥三次。將盒內農藥倒入玻璃試管，將每個試管排放一齊即可看出農藥撒佈狀況。

找出紙盒內農藥量為中央收集點紙盒內農藥量一半的收集點位置，該收集點與撒佈機中央點距離的兩倍即為有效撒佈寬度。

農藥混合與裝填

合適的充分與仔細混合農藥的方法有助於施藥作業。先裝滿半桶水，啟動幫浦，倒入確量農藥之後再灌滿藥桶。

使用溶解性農藥時，仍然先裝滿半桶水，並用小桶預先溶解攪拌農藥再倒入藥桶內。清洗小桶三次並將殘液倒入藥桶之後再灌滿藥桶。

桿式噴藥機藥桶農藥量的計算方式為（1）決定每桶藥劑施藥面積（A），其方法為將藥桶容量除以每公頃施藥量（公升/公頃）。（2）將每公頃施藥量乘以每桶施藥面積，即可求得每桶應加入農藥量。

常用公式

✡ 車速

$$(\text{公里/時}) = \frac{\text{距離(公尺)} \times 1000}{\text{時間(秒)} \times 60}$$

✡ 不同車速下的施藥量

$$(\text{公升/公頃})_2 = \frac{(\text{公升/公頃})_1 \times (\text{公里/時})_1}{(\text{公里/時})_2}$$

✡ 施藥量改變後的車速

$$(\text{公里/時})_2 = \frac{(\text{公升/公頃})_1 \times (\text{公里/時})_1}{(\text{公升/公頃})_2}$$

✡ 改變噴嘴壓力後之施藥量

$$(\text{公升/公頃})_2 = (\text{公升/公頃})_1 \times \sqrt{\frac{(\text{壓力})_2}{(\text{壓力})_1}}$$

✡ 噴嘴壓力

$$(\text{壓力})_2 = (\text{壓力})_1 \times \left[\frac{(\text{公升/公頃})_2}{(\text{公升/公頃})_1}\right]^2$$

✡ 噴嘴流量

$$(\text{公升/分})_2 = (\text{公升/分})_1 \times \sqrt{\frac{(\text{壓力})_2}{(\text{壓力})_1}}$$

註：以上公式中括弧標示 1 代表量測值，2 代表調整設定值。

Orchard Sprayer Calibration

Measured Release Method for Airblast or High-Pressure Sprayers. Due to the air blast or high pressures of larger sprayers, it is not possible to collect ejected liquid into a container. Therefore you must measure the output of the sprayer over a period of time by determining how much water was used.

Start by moving the sprayer to a level surface and fill the tank to its maximum with clean water; liquid must be at a level that can be duplicated when refilling. A convenient technique is to fill the tank with clean water to the point where it just begins to overflow. Use low-volume, low-pressure water, such as from a garden hose, for topping off the tank. Check for leaks around tank seals and in hoses. All nozzles must be clean and operating properly or the results will be inaccurate.

Stand upwind and operate the sprayer at its normal operating speed and pressure. Open the valves to all nozzles, starting a stopwatch at the

FIGURE 11-5.

It is not possible to collect the sprayed liquid from some types of sprayers. To determine the amount of liquid expelled by these sprayers: (1) fill the tank to a known level; (2) run the sprayer under normal conditions for a timed period; and (3) refill the tank to its original level, measuring the amount of water used.

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same time. Continue to run the sprayer for several minutes, then close the valves to all nozzles and record the elapsed time

If the tank has been calibrated and marked, the amount of liquid used will be apparent or can be determined with a calibrated dipstick. Otherwise, use a flow meter attached to a low-pressure filling hose and refill the sprayer to the original level. Record the gallons of water used; this volume is the amount of liquid sprayed during the timed run. Repeat this process two more times to get an average of sprayer output. Determine the gallons-per-minute output of the sprayer by using the calculations shown in Table 11-8.

TABLE 11-8.

Calculating Gallons-per-Minute for High Pressure Sprayers.

1. Record the elapsed time during each trial run and the amount of liquid sprayed:

EXAMPLE:

Run #	Time	Volume
1	1 min 45 sec	37.5 gal
2	1 min 30 sec	33.5 gal
3	1 min 50 sec	38.0 gal

2. Convert the time from minutes and seconds to minutes by dividing the seconds by 60 and adding this decimal to the minutes.

EXAMPLE:

Run #	min	sec	sec/60	= min
1	1	45	0.75	1.75
2	1	30	0.50	1.50
3	1	50	0.83	1.83

3. Divide the collected gallons for each run by the minutes, resulting in gallons-per-minute.

EXAMPLE:

Run #	gal/min = gpm
1	37.5/1.75 = 21.4
2	33.5/1.50 = 22.3
3	38.0/1.83 = 20.8

4. Add all the gallon-per-minute figures and divide this total by the number of runs (3 in this example) to get the average gallon-per-minute output.

EXAMPLE:

Run #	gpm
1	21.4
2	22.3
3	20.8
Total =	64.5

64.5/3 = 21.5 gpm average output

Width of Spray Swath. The final measurement needed to complete calibration is the width of spray swath being applied by the sprayer.

If the sprayer is used to apply pesticides to crop plants in an orchard or vineyard and plants on both sides of the sprayer are treated with one pass, the spray swath is equal to the width of the tree or vine row (Figure 11-12). But if spray is being applied only out of one side of the sprayer and the sprayer is moved along both sides of the tree or vine row, the swath is one-half the width of the tree or vine spacing

Use a tape measure to determine tree or vine row width; take several measurements within the orchard or vineyard to check if row spacing is uniform and consistent; average the results if any variation is found

To adjust an air blast orchard or vineyard sprayer to apply a given volume of water per acre, it is convenient to know the number of trees or vines per acre. After a tank of known volume is sprayed out, the number of trees or vines completely sprayed can be counted and the proportion of an acre covered is then easily figured. Travel speed can be increased or decreased slightly to apply less or more liquid per acre, or nozzle sizes can be changed.

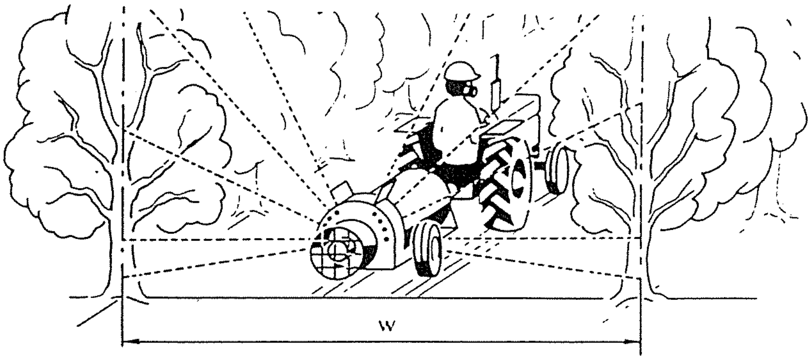


FIGURE 11-12.

In orchards or vineyards, if plants on both sides of the sprayer are being sprayed simultaneously with an air blast sprayer or high-pressure boom sprayer, the swath width is the distance between plant rows.

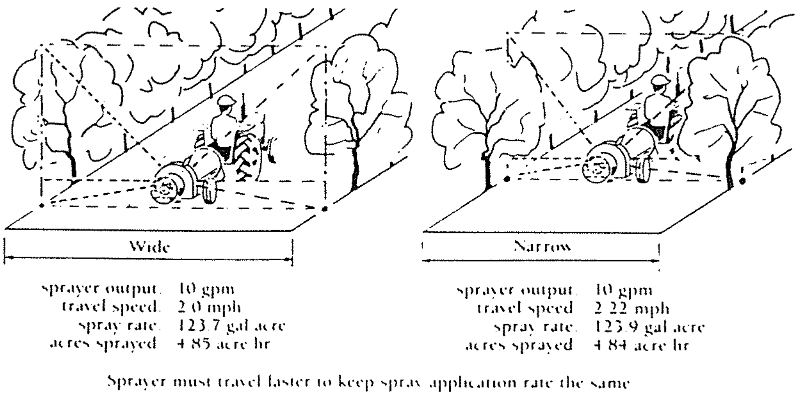


FIGURE 11-18

Changes in row spacing in an orchard or vineyard affect the amount of spray being applied per acre. Increasing or decreasing ground speed can accommodate for the difference in spacing so the correct amount of pesticide per acre will be applied. Variations in the size of trees or vines may also influence the rate of application.

TABLE 11-11.

Orchard Sprayer Calibration Worksheet. A worksheet such as this can be helpful in recording and computing the figures necessary for calibration. Similar worksheets can be developed for other types of sprayers. (In this example, notice the difference between the rated output of the nozzles and the actual output. Nozzles are worn).

ORCHARD SPRAYER CALIBRATION

Grower: D. BROWN Date: 1-29-88 Sprayer Type: AIRBLAST

CHECK:
- ☑ 1. Filter screens and strainers clean?
- ☑ 2. Tank clean and free of scale and sediment?
- ☑ 3. Pressure gauge operating?
- ☑ 4. Nozzles working properly?

Sprayer operating pressure: 100 psi

I-A. GALLONS/HOUR:
(Method 1 – using nozzle chart from manufacturer's catalog)

Nozzle Size		Number (N)		Rated Output (gallons/minute)		Minutes Per Hour		Gallons Per Hour
D2-25		8	×	0.25	×	60	=	120
D4-25		8	×	0.45	×	60	=	216
			×		×	60	=	

TOTAL GALLONS PER HOUR = 336

I-B. GALLONS/HOUR: (Method 2 – measurement)
1. Fill sprayer to verifiable level.
2. Run sprayer for a measured period of time (T), spraying under the same conditions as in the orchard. T = 3.53
3. Refill sprayer, measuring the amount of water used (GAL) in gallons. GAL = 20.4
4. Calculate: gallons/hour = (GAL × 60)/T

TOTAL GALLONS/HOUR = 346.7

II. MILES/HOUR:
1. Establish distance (D) in feet. D = 253
2. Measure elapsed time for sprayer to travel the distance. Make 3 runs and average results.
   a. First run: Time = 1.05 minutes.
   b. Second run: Time = 1.15 minutes.
   c. Third run: Time = 1.13 minutes.
3. Average of three runs (T) = 1.11 minutes.
4. Calculate miles per hour:
   MPH = (D/T)/88 MPH = 2.59

III. ACRES/HOUR:
1. Measure width of tree row (W) in feet. W = 22
2. Calculate miles per acre:
   miles/acre = (43560/W)/5280 MILES/ACRE = 0.375
3. Calculate acres per hour:
   acres/hour = MPH/(miles/acre) ACRES/HOUR = 6.91

IV. GALLONS/ACRE:
(gallons/hour)/(acres/hour) = gallons/acre GALLONS/ACRE = 50.17

V. ACRES/TANK:
Tank size = 500 gallons/tank
(gallons/tank)/(gallons/acre) = acres/tank ACRES/TANK = 9.97

VI. AMOUNT OF PESTICIDE/TANK:

Recommended amount of pesticide/acre = 2.5 lb.

(pesticide/acre) × (acres/tank) = pesticide/tank

PESTICIDE/TANK = 24.9 lb.

VII. CALIBRATION CHECK:

1. Tree spacing (S) = 22 × 22 feet — S = 484
2. Trees per acre (T) = 43560/S — T = 90
3. Count the actual number of trees sprayed (N) with one tank: — N = 918
4. Actual acres sprayed = N/T — ACTUAL ACRES = 10.2
5. Calculated acres per tank (from "V" above) — CALCULATED ACRES/TANK = 9.97
6. Percent accuracy = calculated acres/actual acres × 100 — ACCURACY = 97.7%

Second Method

Calibrating Air Blast Sprayers

Calibrating air blast sprayers is very similar to boom sprayers; the main difference is in how the amount of spray is measured. Since it is very difficult to collect the spray output from an air blast sprayer, the amount sprayed over a given area can be measured as follows:

1. Fill the sprayer completely or to some mark on the inside of the tank with water. Place a marker on the ground next to where the sprayer wheels are sitting so that the sprayer can be returned to this exact same spot.

2. Measure and mark off a test course and measure the width of the swath covered by the air blast spray. The test course should be at least an acre.

3. Spray the test course.

4. Return the sprayer to the place it was filled and measure the amount of water it takes to refill the sprayer to the mark established in Step 1.

5. Convert the amount determined in Step 4 to gallons per acre using the following equation:

$$\frac{\text{Gal}}{\text{Acre}} = \frac{\text{Total Water Sprayed (Gal)}}{\text{Course Length (ft)} \times \text{Swath Width (ft)}} \times \text{Conversion Factor (F)}$$

The conversion factor (F) is used to transform the amount measured in the test to gallons per acre. For this equation the values used for the conversion factor are as follows:

F = 340.3, when the amount determined in Step 4 is in fluid ounces;

F = 5,445, when the amount determined in Step 4 is in pints;

F = 10,890, when the amount determined in Step 4 is in quarts;

F = 43,560, when the amount determined in Step 4 is in gallons;

For example, 50 gallons of water were applied in a calibration test that covered a course 800 feet long and 30 feet wide. The gallons delivered per acre is 90.75 gallons (50/800/30 × 43,560).

6. Calculate the number of acres that can be treated by one tankful by the following equation:

$$\text{acres treated per tank} = \text{tank capacity (gallons)} \; / \; \text{application rate (gallons/acre)}$$

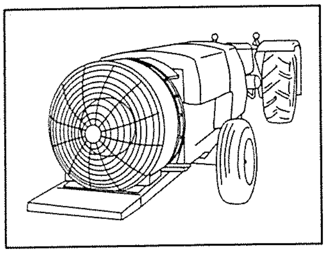
Using the value of 90.75 gallons per acre determined in the above example and a sprayer tank size of 400 gallons, the number of acres that can be treated by one tankful is 4.41 acres (400/90.75).

7. Determine the amount of pesticide to be added to the tank by multiplying the number of acres treated with one tankful by the recommended pesticide rate. If the recommended rate of pesticide is 1 quart/acre in the above example, 4.40 quarts or 1 gallon plus 12 fluid ounces of formulated pesticide would be added to the tank.

NRAES

ORCHARD SPRAYING: GETTING RESULTS

—— A Guide to Orchard Sprayer Calibration ——



Typical air-blast sprayer.

Understanding sprayer performance could mean the difference between adequate pest control and disease management—and disaster. Accurate pesticide application depends on the proper maintenance and calibration of your sprayer.

USDA and EPA guidelines state that growers should apply pesticides within 5% of the labeled rate, but studies conducted by the Cornell Cooperative Extension System showed that many growers applied either more or less material than intended. That cost them control and money.

Many of the newer pesticides are applied at rates of ounces per acre, which makes accurate spraying even more important. For optimum performance, check your sprayer's operation before each application season and preferably during the season as well.

Here are some ways to ensure your sprayer is calibrated and operating properly.

Precalibration Check

Before calibrating, check the sprayer.

STEP 1

Pull out the filter or strainer and clean it if necessary (figure 1). A dirty strainer can restrict the flow and reduce spraying pressure of the pesticide solution.

STEP 2

Check the nozzles on the nozzle manifold. Remove each of the nozzles and clean them, removing any obstructions with an old toothbrush or other soft brush (figure 2).

STEP 3

Inspect the fan to see that the blades are not damaged. Check for dirt or other obstacles that may reduce airflow (figure 3).

STEP 4

With the fan on and the spray off, check the airflow around the fan outlet by moving your hand around the nozzles. Adequate airflow around all the nozzles is necessary to deliver the spray to all parts of the trees.

STEP 5

Check for leaks by running the sprayer with clean water. If there are leaks, repair them before filling with pesticide solution.

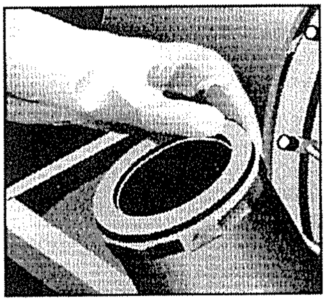


Figure 1. Filter check.

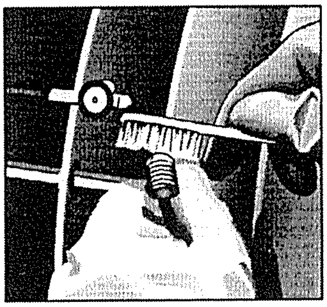


Figure 2. Nozzle cleaning.

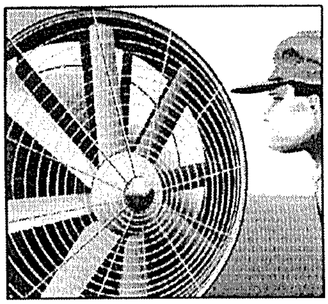


Figure 3. Fan check.

Field Calibration

After the precalibration check, it is time to calibrate your sprayer. Throughout calibration, remember to use only clean water in the tank for safety. Use personal protective clothing, such as a spray suit, gloves, boots, and goggles.

A common way to calibrate is to spray a known area, then check the tank to determine the amount of water used. To calibrate by area, select an area larger than 1 row, but smaller than 5 acres. Know the exact size of the check area sprayed for accurate results.

Set up a permanent calibration course with trees as markers. Calculate the area of the course using the following formula:

$$\text{Calibration course area (acres)} = \frac{\begin{pmatrix}\text{distance}\\ \text{between}\\ \text{rows}\end{pmatrix} \times \begin{pmatrix}\text{distance}\\ \text{between}\\ \text{trees}\end{pmatrix} \times \begin{pmatrix}\text{number}\\ \text{of trees}\\ \text{per row}\end{pmatrix}}{43{,}560\ \text{ft}^2/\text{acre}}$$

(distance is measured in feet)

Determine gallons of spray needed per acre. The intended application rate is determined by following label instructions and the size and shape of the tree. Spray within the test area and accurately measure the amount of water used. If the actual amount of water used equals the needed amount, your sprayer is calibrated correctly. This technique is a good way to quickly check sprayer operation, but it does not help identify which operating parameters are out of adjustment. A more accurate calibration method involves checking all factors that influence application accuracy.

Travel Speed

Travel speed influences the accuracy of the application as well as the spray distribution in the trees. If you travel too fast while spraying, you may not put enough material on the trees and the spray pattern may be distorted. If you travel too slowly, you may be applying too much spray. Both negatively affect coverage and performance. Travel speed is influenced by a number of factors—operating gear, engine speed, tire slippage, ground conditions, and the power requirements of the sprayer.

One way to check travel speed is to drive the tractor and sprayer over a test course in an orchard. Know the travel speed to the nearest tenth of a mile (figure 4).

- Measure a test course of 100–200 feet. The longer the course, the more accurate the speed calculated. Mark the beginning and the end of the course with temporary markers, such as flags, or more permanent markers, such as trees.
- Fill the sprayer tank with water, ⅓ to ⅔ full, to simulate average field conditions.
- With the sprayer operating at field pressure, travel at your spraying speed before you reach the beginning marker. This means that you will travel at a consistent speed throughout the course.
- Have a second person walk alongside the tractor and sprayer with a stopwatch to note the time elapsed between the beginning and the end of the course.
- Repeat the test and average the results of the two runs.
- Use the following formula to determine travel speed:

$$\text{Speed (MPH)} = \frac{(\text{distance in feet}) \times (60)}{(\text{time in seconds}) \times (88)}$$

MPH = miles per hour
60 and 80 = constants to make units consistent

- If the measured travel speed is different from the intended speed, change the gear or throttle settings to achieve the desired speed. Do not adjust the throttle speed so that it reduces spray pressure or fan speed.

Pressure Check

The pressure of the spray solution at the nozzles is a key to applying the correct amount of material to the tree. Pressure affects droplet size, which influences coverage and drift. The pressure that counts is at the nozzle where the spray solution is converted into droplets, not at the pump.

To check nozzle pressure, use an accurate pressure gauge (figure 5). Liquid-filled gauges are recommended. Place the pressure gauge on the nozzle fitting farthest from the pump and turn the sprayer on. If the pressure is lower at the nozzle than specified, you may need to increase pressure at the regulator to obtain the required pressure at the nozzle.

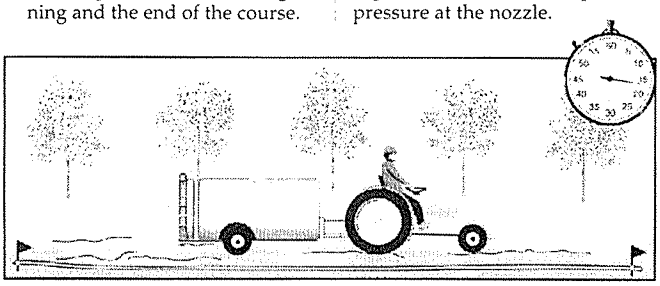


Figure 4. Estimating travel speed.

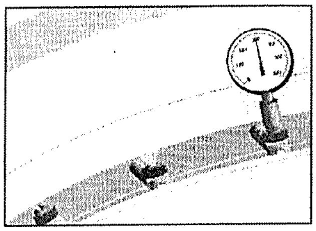


Figure 5. Checking nozzle pressure with a pressure guage.

Nozzle Output

A nozzle is designed to deliver a specific number of gallons per minute when operating at a specific pressure. It is important to select the type of nozzle you need for each particular application based on the nozzle flow rate, spray pattern, and spray coverage required.

Obtaining the desired flow rate from nozzles is fundamental to accurate spray application. Worn nozzles can apply more spray material than is needed, which means overapplication and wasted money. A nozzle obstruction can reduce or stop delivery—parts of the orchard will not receive enough spray.

You can check actual nozzle output by using a flow meter (figure 6). A flow meter fits over the nozzle opening and, when the sprayer is running, will show the flow rate through the nozzle in gallons per minute (GPM).

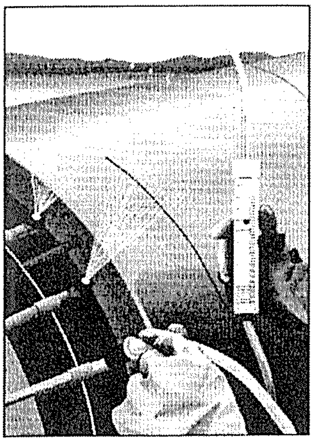


Figure 6. Using a flow meter to measure nozzle flow rate.

Another way to check flow rate is to connect hoses to each of the nozzles, turn on the sprayer, and direct the hose flow into pails or barrels (figure 7). Measure the gallons of water from each nozzle or an entire side of the sprayer over a brief period. Divide the number of gallons collected by the total collection time to determine the flow rate through the nozzle in gallons per minute. It is important to make all measurements as accurately as possible.

If the nozzle flow rate is more than 10% different from the desired flow rate for the measured nozzle pressure, replace the nozzle.

This technique also works well on sprayers that use air-shear nozzles. The hoses that deliver spray solution to the nozzles can be directed into collection containers to measure sprayer output.

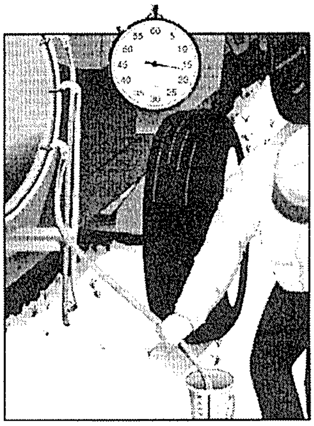


Figure 7. Measuring nozzle flow rate.

Calculating Application Rate

If you know the total nozzle output, travel speed, and row spacing, use the following formula to calculate the application rate or gallons per acre sprayed:

$$\text{Gallons per acre} = \frac{\left(\text{nozzle output in GPM}\right) \times \left(495\right)}{\left(\text{travel speed in MPH}\right) \times \left(\text{space between rows in feet}\right)}$$

GPM = gallons per minute
MPH = miles per hour
495 = constant to make units consistent

Correcting Sprayer Output

The following equations can be used to determine adjustments to sprayer operation that will provide the required output:

$$\text{MPH needed} = \left(\text{MPH measured}\right) \times \left(\frac{\text{GPA measured}}{\text{GPA needed}}\right)$$

$$\text{PSI needed} = \left(\text{PSI measured}\right) \times \left(\frac{\text{GPA needed}}{\text{GPA measured}}\right)^2$$

MPH = miles per hour
GPA = gallons per acre
PSI = pounds per square inch

Use a different type of nozzle if you need to make great changes to sprayer output. Consult nozzle manufacturers or their catalogs to see how pressure changes affect droplet size.

Another method of adjusting the application rate is changing the pesticide-to-water mix. Always stay with recommended label rates.

Field Checks

While spraying in the orchard, check the sprayer to see that the nozzles are operating properly. From the tractor seat, you can see if a nozzle is blocked or if the spray patterns are distorted. Be sure that the spray is reaching all areas of the tree. If it is not, adjust the fan speed or air deflectors to improve spray coverage.

To check the angle of the air discharge, attach a length of ribbon or other streamer to the top and bottom air deflectors on both sides of the sprayer and at the top and bottom of the tree foliage. Operate the sprayer fan and adjust the air deflectors on the sprayer until the ribbons on the sprayer and the tree are aligned (figure 8).

To check spray coverage, staple water-sensitive paper along a test row and spray the row with water. Changes in the color of the paper indicate whether the spray reached that area of the tree. The spots of changed color on the paper are a good indication of droplet size and the amount of spray coverage.

Application Tips

- Always follow label directions with pesticide applications.
- Keep the sprayer running just until the trees at the ends of the rows have been treated.
- Use wear-resistant nozzles.
- Remember that spray controllers or computers ensure accurate sprayer output, but they cannot compensate for changes in droplet size and spray pattern (which result in poor spray coverage) as nozzles wear.
- Avoid spraying when it is too windy.
- Adjust fan speed to keep the spray within the spray row.
- Adjust the sprayer operation for different tree sizes and canopy densities.
- Prune the trees to allow good spray movement to all parts of the trees.
- Always use personal protective clothing and equipment.

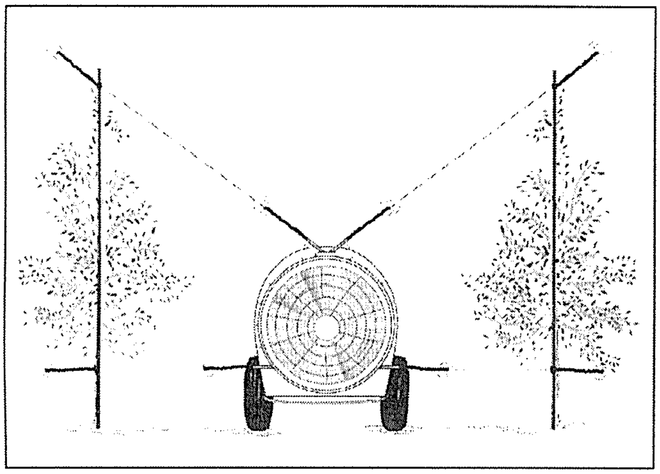


Figure 8. Checking the angle of the air discharge.

Summary

Following these practices—conducting a precalibration check, calibrating, and checking during spraying—is an important step toward more efficient, responsible, and profitable production.

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RECENT TRENDS IN AGROCHEMICAL APPLICATION IN THE U.S.A.

H. Erdal Ozkan Robert D. Fox[1]

ABSTRACT

New pesticides are more potent and require more precise application. Research is continuing in universities, government, and industry to develop new methods and equipment to achieve maximum efficiency in the use of pesticides while minimizing the potential risk to the applicator and the environment. This paper summarizes major developments in spray application technology research and recent developments to reduce spray drift and to improve application efficiency. These developments include low drift nozzles that produce larger drops, air-induction, electrostatic, and air-atomizing nozzles. Other drift reduction technology discussed includes air-assisted sprayers, boom shields, and tunnel sprayers. Technology to support precision farming includes variable rate sprayers, GPS and GIS techniques, closed chemical transfer systems, and flow control systems. New orchard spray technology include tower sprayers and canopy sensing techniques. Biological pest control agents often require special delivery systems to prevent damage to the living organisms being distributed on the plant canopy.

INTRODUCTION

About 1/3 of all pesticides produced worldwide are sold in the USA (NACA, 1993). Pesticide usage in the U. S. has been relatively stable at about 500 Million kg of active ingredient during recent years. Due to increasing concerns about crop production costs and environmental pollution, it is essential to apply pesticides with precision and care. New pesticides are more potent and require more precise application.

Current chemical application methods and equipment have improved application accuracy considerably; however, efficiency is still low and many unanswered questions remain. Research is continuing at universities, government, and industry to develop new methods and equipment to achieve maximum efficiency in the use of pesticides while minimizing the potential risk to the applicator and the environment.

Pesticide application is a complex operation and it requires more skills, management and precision than many other operations in crop production. It involves many critical steps such as uniform mixing of pesticides in the tank, efficient transportation of pesticides from the spray equipment to the target, retention of pesticides on the target and finally

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uptake of the pesticide active ingredients by plants, insects, or diseases.

The least efficient aspect of liquid pesticide application is transporting spray droplets from the nozzle to the target. Research indicates that often only a small portion of the intended chemical dose actually reaches the target and contributes to the desired biological effect (Pimentel and Levitan, 1986). A portion of the spray never reaches the target. This problem of spray drift remains a serious health and safety problem. Recently, reduction of spray drift has been a focus of many research projects in universities and research stations around the world, because reduced spray drift not only improves application efficiency, but it also reduces environmental pollution.

OBJECTIVES

The objectives of this paper are to provide a summary of major developments in spray application technology research and development in the U.S.A. This includes advances directed toward reduced spray drift and improved application efficiency. Although important developments in spray technology has taken place all over the world, the summary provided below includes mostly the developments taking place in the U.S.A.

I. Research and Equipment Development to Reduce Spray Drift

Although complete elimination of spray drift is very difficult, its magnitude can be reduced significantly if factors that increase the risk of drift can be altered or eliminated. Smith et al. (1982) discussed variables affecting drift in detail. Weather conditions, especially the wind, which the applicator cannot control, play an important role in the generation and movement of drift. Factors under operator control include chemical formulation and application parameters, including selection and proper operation of the spray equipment. The most important application factor influencing drift is the size of droplet sprayed. Small droplets, if deposited on the target, provide better coverage and this usually results in increased control of some pests. However, small droplets are susceptible to drift. Zhu et al. (1994) have shown that for typical applications with boom type sprayers, droplets of 100 μm or less often drift out of the intended swath, and 50 μm or less diameter droplets, completely evaporate before reaching the target.

When using conventional spray equipment, the total volume of spray made up of droplets less than 100 μm in diameter is relatively small, but even such small amounts may sometimes cause serious heath problems and/or damage crops in nearby fields. Several possible solutions have been suggested to combat spray drift. Most of these solutions are centered around three major concepts: 1) not spraying at all when the weather conditions are not favorable, 2) reducing the volume of spray contained in small droplets, 3) altering the flight paths of small spray droplets by mechanical means to increase efficiency of deposition on the target.

Although most operators are aware of spray drift and the problems associated with it, treatment of a field during unfavorable weather conditions may be unavoidable when the pest population is at a level such that further delay in spraying may result in total crop

loss. Realizing this fact, most researchers and equipment manufacturers have been focusing their attention to developing equipment to reduce drift.

Some manufacturers have introduced nozzles that reduce the volume of spray contained in small droplets. Other companies have developed chemical additives called "drift retardants" to achieve the same goal: reducing the volume of spray contained in small droplets. Research has proven that adding these products to the spray mixture creates a change in some of the basic physical characteristics such as surface tension, viscosity and density of the mixture causing an increase in volume median droplet size for a given atomizer (Richardson, 1974, Bouse et al., 1990). Ozkan et al. (1993) investigated the effects of various drift retardant chemicals (Direct, Driftgard, Formula 358, Nalco-trol, and Target) on droplet size, spray pattern, and spray drift reduction. The results of this study indicated that, the mixture of water and Nalco-trol (at recommended rates) provided the largest increase (63%) in volume median diameters (VMD) in comparison to that of water. Percent increase in VMD with Direct, Target, Driftgard, and Formula 358 were much smaller, 59.8, 38.9, 28.6, and 3.5%, respectively. All drift retardants caused spray patterns with greater volume in the center than for sprays with water only. Although their chemical make-ups are similar, there are over 30 "drift retardants" used by the applicators in the USA.

Several recent developments have been aimed at modifying existing equipment to increase deposition efficiency of the more effective small droplet while reducing the potential for drift. In general, this has been accomplished by using either air-assist technology or some kind of shield or shroud to overcome the drift-producing air currents and turbulence that occur near the nozzle during spraying.

<u>Nozzle classification system</u>

The American Society of Agricultural Engineers (ASAE) has recently accepted a new standard that defines several classes of droplet sizes produced by nozzles. This system is patterned after the British Crop Protection Council (BCPC) guidelines that have been used in Europe for several years. Defined droplet size classes include very fine, fine, medium, coarse, very coarse, and extremely coarse. In this system, the boundaries between classes are defined by a group of "standard" nozzles using the drop size versus cumulative volume plot. This makes nozzle class definitions independent of the droplet size instrument used for measuring droplet size. A set of standard nozzles is available for laboratories that need to establish size classifications for their specific droplet-sizing instrument.

In about the year 2000, agricultural pesticide manufacturers will begin to specify, on the pesticide label, the smallest nozzle class to be used with each pesticide. This system is intended to reduce drift by assuring that nozzles applying spray produce a specified, minimum droplet size. In some cases, the label may specify different nozzles for specific wind speed conditions, that is, a coarse nozzle must be used if wind speed is above 20 km/hr, but a medium nozzle may be used if wind speed is below 10 km/hr. Nozzle manufacturers catalogs will contain information about the droplet size

classification for each nozzle, at each operating pressure.

A) New Atomizers/Nozzles

"Low-Drift" Nozzles

Most major agricultural nozzle manufacturers have recently come up with "Low-Drift" nozzles which are designed to create larger droplets at the same flow rate and operating pressure than comparable, standard flat fan (SFF) nozzles. This has been accomplished by adding a pre-orifice to the nozzle tip assembly just ahead of the conventional discharge orifice. SFF tips have a straight bore that carries liquid from the boom to the tip. With these new "low-drift" nozzles (Figure 1), liquid enters through a small orifice

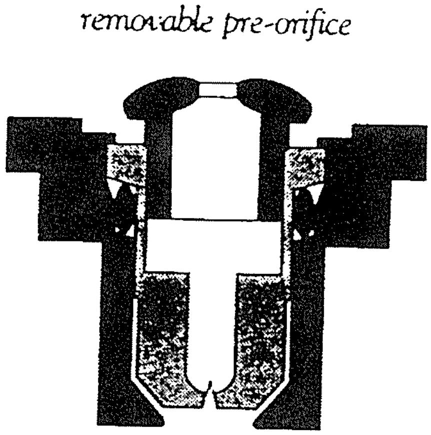

Figure 1. DriftGuard nozzle

and flows into a chamber machined into the nozzle body. The liquid then flows from this chamber into a short passage and out of the discharge orifice. The pre-orifice reduces liquid velocity, creating larger droplets which should significantly reduce drift. According to one of the manufacturers of these nozzles, their "low-drift" nozzle tips reduce the number of droplets smaller than 200 μm by 50 to 80 percent. In addition to "low-drift" nozzles, Spraying Systems Co. has introduced a new flat-fan nozzle ("Turbo TeeJet®") that can be used for the same applications as a SFF nozzle. The advantage of the new "Turbo TeeJet" nozzles are twofold: they can be operated at a wider range of pressure (207 to 414 kPa with SFF vs. 103 to 621 kPa with Turbo TeeJet), and they produce fewer drift-prone droplets compared to the same size SFF.

"TurboDrop®" Nozzles

These nozzles are originally manufactured in Germany by Agrotop Company, and distributed to the US by Greenleaf Technologies (Covington, Louisiana). The TurboDrop nozzles (Figure 2) are designed to produce larger droplets while reducing the

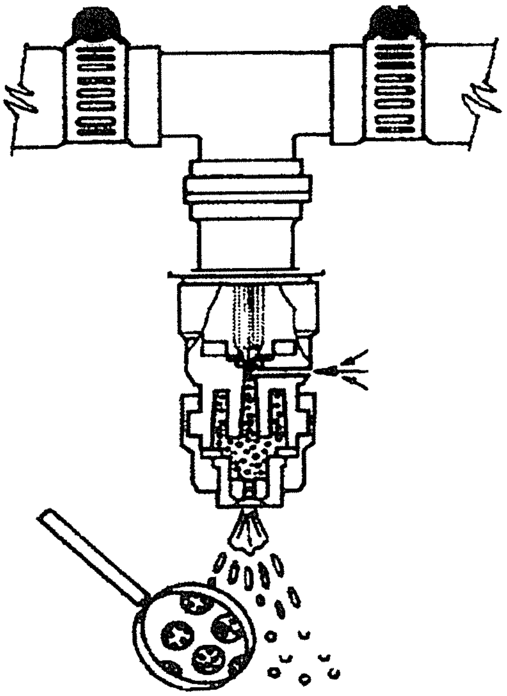

Figure 2. TurboDrop nozzle

percentage of fine droplets. As with other "low-drift" nozzles, TurboDrop nozzles also have a pre-orifice ahead of the exit orifice to reduce the pressure exerted on the liquid at the point of discharge. The liquid flow rate is controlled by a ceramic orifice plate located at the bottom of top section. As the liquid passes through the orifice plate, a region of low pressure is created by this venturi, which results in air being drawn into the nozzle body. Air and spray solution are blended in the mixing chamber. As the liquid is discharged from the nozzle tip, spray droplets with trapped air bubbles are produced. The bottom (exit) nozzle does not control the output rate. It is there to form the desired pattern. Therefore, a standard flat fan tip with a larger orifice can be used to produce larger droplets. Upon leaving the nozzle orifice, the air included in the droplets expands which makes droplet size somewhat larger, causing an increase in droplet velocity. In addition to producing larger droplets, producing higher velocity droplets further improves the chances of droplets reaching the target before becoming subject to drift. Another benefit mentioned by the manufacturer of this nozzle is that large droplets shatter and splatter on contact, causing the small air-filled drops to spread out on the target for better coverage. According to its manufacturer, TurboDrop nozzles reduce the drift of small droplets considerably.

Our studies have shown little or no air bubbles in droplets of pure water. However when a surfactant was added to the sprayed mixture, spray droplets did contain entrained air bubbles.

Air-Induction (AI) nozzles

Most agricultural nozzle manufacturers have developed and are now marketing air-induction nozzles. These nozzles all use the same principle as the TurboDrop nozzles. They have a pre-orifice, then a venturi section which draws are from an air-inlet port, and a final mixing chamber before the air-spray mixture leaves the nozzle through a nozzle tip. The nozzle tip atomizes the spray and develops the spray pattern. These nozzles reduce the percentage of driftable droplets (less than 150 μm) and should reduce drift problems. They have become very popular with farmers in Europe and the USA. We have found that blocking the air-inlet port does not change the droplet size spectra. Our studies show that using larger orifice nozzles such as Turbo-TeeJet under lower system pressure will produce similar droplet size spectra and drift patterns.

Electrostatic atomizers

Electrostatic charging of small droplets has been considered as a way to increase deposition efficiency and reduce drift of small droplets. Although research on electrostatic spraying in industrial applications has been conducted for more than 50 years, the use of charged sprays was not extended to agriculture until early 1970's. Several electrostatic atomizers have been designed and marketed, especially in Europe. However, these atomizers have not gained wide acceptance by farmers. Currently there are two companies (ESP, Melroe, Bismark, North Dakota, and Electrostatic Spraying Systems (ESS) Inc., Watkinswille, Georgia) manufacturing and marketing sprayers that are capable of discharging electrostatically charged droplets.

Until recently all electrostatic sprayers have used an inductive charging technique which involves passing spray liquid through an electrostatically charged ring or plate. During this process, the electric charge is transferred to the droplets as they pass through this electrical field. Some companies such as ESS also used air assist in addition to charging of droplets to improve penetration of droplets and better coverage on both upper and under-side of the target leaves. The airflow rate at the atomizer is 17 to 20 m^3 /min. Approximately 7.5 to 40 kW of power is required to run the compressor which produce the air supplied to the atomizer. The latest version of this commercial sprayer uses lower air pressure for the atomizing nozzle. This permits the use of a lower-energy blower to replace the air-compressor.

The ESP System uses the principle of contact charging for electrostatically charging of droplets. With this system, the spray liquid is charged before it reaches the nozzles. The ESP System delivers a 40000-volt charge to the spray liquid while it is in the charging tank. This allows the producer to use any standard hydraulic nozzle recommended for an application. It has no electrical wires going to individual nozzles and since it does not use air-assistance, there is no need for an air compressor.

Although it has been demonstrated in research trials that electrostatic sprayers work well under certain conditions, this technology has not consistently produced good results. Electrostatic sprayers have not yet been widely accepted by the producers in the USA,

mostly because of higher initial costs of electrostatic atomizers. However, increased public concern about the environment and the push towards reduced pesticide consumption are likely to provide the impetus to stimulate further adoption of electrostatic spray systems.

Air Atomizers

When using standard hydraulic nozzles, as the applicator changes travel speed, an automatic rate controller adjusts spray pressure to maintain the desired flow and application rates. Changes in pressure also influence droplet size. As speed increases, to keep the application rate per hectare constant, an automatic controller increases system pressure which produces a larger flow rate with smaller droplets. When the operator slows down, pressure decreases and droplet size increases.

Increasing droplet size is a common strategy to reduce drift when working with conventional hydraulic nozzles. Usually, this is accomplished by increasing spray volume and/or decreasing pressure. Unfortunately, higher spray volumes require larger sprayer tanks and/or more frequent refills. Also, larger droplets may not be suitable for the type of coverage required by certain chemicals. Recently introduced air atomizer nozzles may provide a solution to this dilemma.

Air atomizers may use just air pressure, or both air and liquid pressure to atomize and carry the spray solution to the target. The sprayer operator can vary droplet size independently of nozzle flow rate. In windy conditions, larger droplets can be used to reduce drift. Where a thorough coverage is required, (both upper-side and under-side of the leaves covered) smaller droplets can be generated.

Currently two true air atomizers are available in the U.S.A. The air atomizer "AirJet®" (Figure 3), manufactured by Spraying Systems Co. (Wheaton, Illinois), works by mixing

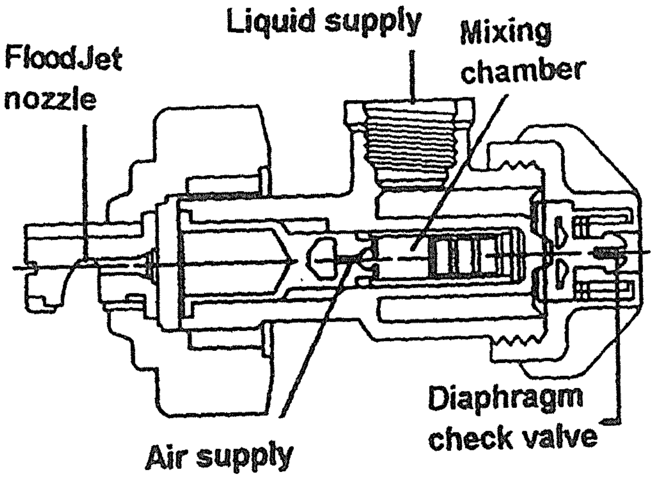

Figure 3. AirJet nozzle

air with the spray solution inside the nozzle to atomize the spray. A metering insert

determines the liquid capacity, as pressure increases, the liquid volume decreases. An on-board compressor provides about 4 m^3/s air supply to the atomizer. The air enters the nozzle body through a 3 mm port from one side of the atomizer body. By adjusting both air and liquid pressures, the operator can control droplet size over a wide spectrum without changing nozzles. The AirJet nozzle uses conventional FloodJet® spray tips to create the spray pattern. The recommended distance between atomizers on a spray boom is 50 cm.

The other air atomizer, "Shear Guard™ PLUS" (Figure 4) manufactured by Spray-air

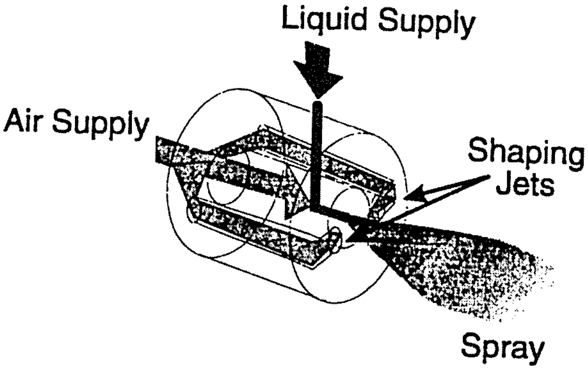

Figure 4. Shear Guard PLUS nozzle

USA Inc. (Grangeville, Idaho), is inserted at 20 cm intervals in a boom assembly that spans from 24 to 28 m. The boom, a hollow fiberglass tube 24 mm in diameter, delivers air from a fan, powered by the tractor PTO, to the atomizer at low pressure (25 to 90 cm of water gage). The air is used to atomize liquid into droplets, as well as to develop a high momentum jet to agitate the crop canopy thereby increasing droplet penetration and coverage. Air travels through the hole at the center of the atomizer as well as two narrow ports on both sides of the center port. The air exiting the side ports is directed toward the center of the main vertical air port where liquid is discharged. The main function of the air coming from the side ports is to give the discharging liquid a spray pattern that is similar to the pattern obtained from a standard flat fan nozzle. Liquid is pumped to each atomizer on the boom via a separate manifold attached to the boom. It is introduced to the air stream in the center of the main air jet port of the atomizer, between the two cross-flow pattern-shaping jets. When the air and liquid meet, the liquid is atomized. An orifice disc is used to control the amount of liquid flow to each atomizer. With Shear Guard™ PLUS, it is possible to choose the droplet size that will give the best performance and still minimize drift. The operator can adjust the velocity of air and thus change the droplet size from the cab regardless of the ground speed. The range of droplet size produced by this atomizer is from 100 to 500 μm.

B) Air-Assisted Spraying

The use of air-assisted boom sprayers for application of pesticides has increased over the last few years. The major factors behind this increased use are concerns related to drift

of small droplets outside the application area, and inefficiency of existing hydraulic nozzles to provide adequate spray coverage on the under-side of leaves.

Several sprayer companies (Hardi Inc., Denmark; Durand Wayland, Inc., USA; Rau Agrotechnic, Germany) have versions of air-assist sprayers. The principle of air-assistance is nearly the same in all three sprayers. An inflatable air tube is positioned just behind the conventional hydraulic boom. Air is forced into the tube using a centrifugal fan. The air exits the inflatable tube through approximately 5 cm diameter holes along the bottom of the air tube, at a slight angle to the vertical (this angle is adjustable on some machines). Droplets are produced by nozzles just ahead of the air tube and entrained in the high velocity air exiting the tube and carried to the target. The air flow rate can be varied or stopped altogether if not needed.

Airtec Sprayer, Inc., USA, uses a 30 cm diameter horizontal aluminum tube to deliver air to individual outlets (short, 7 cm diameter pipes) fitted vertically to the aluminum tube. Standard "ConeJet" type hollow cone nozzles are inserted inside the small air outlet pipes. Air velocity at the nozzle is 80-100 m/s. Nozzles are operated at a pressure of 250-300 kPa.

Howard et al. (1994, 1995) evaluated all currently marketed air-assisted sprayers, including the ones described above, for penetration, drift and deposition of pesticides. Droplet size, leaf coverage, and deposition on the upper- and under-sides of leaves at the top and middle canopy locations were measured and compared to a conventional boom sprayer. Results showed that air-assisted sprayers provided much better coverage on the under-side of the leaves compared to the conventional sprayer. However, they also pointed out that, with air-assisted sprayers, there could be a greater potential for off-target drift of droplets when lower rates of carrier volume and the higher air speeds were used in a bare ground situation. Some small spray droplets can be forced back up into the air and become susceptible to drift, if the crop canopy below is not sufficient to stabilize the energy in high speed air penetrating the canopy.
Although air-assist technology has been proven to be effective in increasing deposition while reducing drift, commercially available equipment using this technology currently has not been adopted by the applicators yet, mostly because of relatively high cost of the equipment.

C) Sprayer Boom Shields

Shields have been considered as economically viable alternatives to expensive air-assist sprayers. Furness (1991) compared a simple shield, mounted vertically in front of a boom with conventional nozzles, with an air-assist system that consisted of a set of rotary sleeve atomizers in the center of a shrouded axial fan. He concluded that shields are "simple, cheap and reliable, with no moving parts, whereas axial fans are complex, expensive and high in power requirement by comparison."
Smith et al. (1982) conducted both laboratory and field experiments to quantify the effects of a mechanical and a pneumatic shield on drift deposits. Results from laboratory tests indicated that a mechanical shield could reduce spray drift deposits by

up to 70%. However, field tests produced mixed results. While one mechanical shield reduced downwind drift deposits by 65%, the same shield under a different sprayer speed/wind speed configuration caused 81% more downwind drift deposits than the conventional boom.

Studies conducted by other researchers (Fehringer and Cavaletto, 1990, Cenkowski et al., 1994, and Wolf et al., 1993) to evaluate effectiveness of shields indicate that most of these devices reduce off-target spray drift. However, the results vary considerably among studies. In addition, experiments conducted in the field are subject to errors due to varying atmospheric conditions. Therefore, a more precise way to compare shield designs such as those discussed in the literature, would be to test them under controlled environmental conditions.

Ozkan et. al. (1996) studied the effect of several types of spray boom shields on spray drift by conducting experiments in a wind tunnel that is 10 m long, 1.5 m wide, and 1.0 m in height. A 3 by 3 m spray patternator table, half of which lies in the wind tunnel, was used to evaluate effectiveness of nine shield designs (Figure 5) by analyzing the spray deposition patterns with and without shields. Flat fan nozzles with 110° of spray angle and 0.6 L/min nominal flow rate (at a pressure of 0.3 MPa) were used for experiments. More information about the wind tunnel and the shields tested is given by Ozkan et al. (1996).

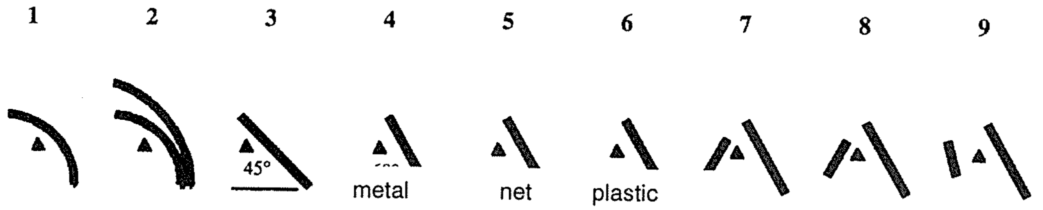

Figure 5. Nine shield designs used by Ozkan et al. (1996)

The performance of all experimental shields were evaluated under two spray pressures (0.15 and 0.3 MPa), and two air flow rates (2.75 and 4.80 m/s) in the wind tunnel. In addition to tests with shields, one set of tests at both pressures and airflow rates was conducted without shields. The volume of liquid collected in all 59 cylinders of the patternator was recorded and analyzed. Following conclusions were reached:

1. All nine shields effectively reduced spray drift from 0.61 L/min capacity nozzles by directing more of the small, drift-prone spray droplets toward the ground. Even the least effective of the shield designs (shields made of a porous material) produced a 13% improvement in deposition of spray on the ground. The double-

foil shield (Shield 2) produced the best performance; it improved spray deposition by 59% in comparison to same nozzles spraying without the shield.

2. The shields were effective even when used with nozzles with higher flow rates (producing fewer small droplets).

3. If applicable, choosing a nozzle with a larger nominal flow rate may be as effective at reducing drift as constructing a costly shield around the spray boom.

D. Tunnel Sprayers

Commercial tunnel sprayers are now available in Europe and USA. These sprayers have a frame covered with sheet metal or plastic that encloses a section of tree or vineyard canopy being sprayed. They are typically 4 or 5 m long and wide enough and tall enough to straddle a row of dwarf trees or a row of grapes. Some sprayers have fans that provide air-assisted spraying, while others have only spray nozzles. Some models collect spray that deposits on the tunnel walls and recycle it through filters, back into the spray tank. Tunnel sprayers enclose the section of the orchard being sprayed, therefore they reduce spray movement out of the sprayed area. Some studies show that more spray is deposited on the ground under the row than with conventional sprayers. Tunnel sprayers are not widely used in the USA because only about 10 percent of the apple trees are small enough for these machines. Most other fruit or nut trees grown in the USA are also too large for practical tunnel sprayers. Vineyards are one crop where this technology could be applied. Some farmers do not like tunnel sprayers due to their size. They are difficult to turn and maneuver in orchards where open space is limited.

II. Other Major Developments in Chemical Application Technology

A. Technology for Variable-Rate Application of Chemicals

On-the-go change of application rate of agricultural chemicals and change of plant population using information provided by satellites orbiting the earth is no longer a theory. Technologies to accomplish these tasks are now available to farmers in the USA and some other countries around the world. Variable-rate application of chemicals has been given many names, including: site-specific farming, prescription farming and precision farming. Major tasks involved in precision farming include: 1) identification of a given location in the field (longitude, latitude, altitude); 2) collecting site-specific information regarding soil physical characteristics, soil nutrient content, areas infested with pests, crop yield, etc.; 3) using computer hardware and software to store this information; 4) processing and analyzing this data; and 5) using proper equipment to do the actual application of chemicals on-the-go in accordance with the information stored in the on-board computer. Many computer software companies have recently introduced a new generation of mapping software.

The location of the field at any given time is determined by using the Global Positioning

System (GPS) of earth-orbiting satellites. Other information related to soil and other management practices is gathered using specific equipment and monitors. And finally, computer software called Geographic Information Systems (GIS) provides a means of graphically presenting, analyzing and interpreting the data, linking management information and records to specific points within a field.

So far, the most popular application of precision farming technology has been in the area of fertilizer application. This technology allows farmers to apply variable fertilizer rates based on the existing fertility of the soil and the crop needs, to each small division of a field. Although not documented yet, the variable rate application of fertilizers is expected to result in a reduction in cost of fertilizer inputs, and a reduction in the potential for water contamination as a result of runoff and/or leaching of fertilizers.

Using soil maps, farmers can alter tillage practices in sections of the field that are prone to erosion or compaction. Again the soil maps and yield data obtained from yield monitors can be used to determine the yield potential of areas in the field. This information can lead to changing fertilizer rates and planting populations to maximize profit and reduce waste.

With new technology using GPS and GIS, it is now possible to identify and isolate weedy areas of the field. By overlying weed maps along with soil maps, farmers can determine proper herbicide rates based on weed pressure, soil type and organic matter content. Using this information and the variable-rate technology, farmers can achieve weed control that uses the right amount of herbicides for each area of the field. Unfortunately, variable rate-application of herbicides for weed control using GPS/GIS technology has not yet been fully implemented.

Profitability of the precision farming technology is still under scrutiny. But savings in cost of inputs when using variable-rate technology is well documented.

B. Marking Systems Using GPS

When working with sprayers with a wide boom, it is difficult to determine the next sprayer path after a turn around. Improper positioning of the sprayer, resulting from inadequate marking of swath, may lead to excessive overlaps and skips that may cause chemical waste or insufficient pest control. Currently, foam or mechanical marking systems are used to identify the area covered during one pass of a sprayer. Now this task can be accomplished by using the GPS or perhaps FM radio signal systems. To use these systems, first a pass is made running the perimeter of the field. Then, using GPS, the location of the sprayer is recorded in one corner of the field. After entering the swath width of the sprayer in the controller, a pass is made across the field. This first pass of the length of the field establishes the "master swath". As the sprayer turns around for the second pass, a light bar indicates (by a series of lights right and left of center) where the sprayer is in relation to the centerline of the master swath.

C. Closed Chemical Transfer Systems

Since current pesticides are more potent than pesticides manufactured only 10 or 15 years ago, they require more care during mixing and handling. The major source of water contamination by pesticides is spills that occur during mixing and transport of pesticides. Although closed chemical transfer systems are not required in the USA, these systems are becoming standard equipment on most currently manufactured sprayers because they reduce the risk of operator exposure to pesticides, and reduce the risk of contaminating the environment. Using closed transfer systems, an operator can automatically meter only the desired portion of liquid product, transfer it to the spray tank and automatically rinse empty containers and the interior of the sprayer tank.

D. "SYNCHRO" - A System for Digital Control of Flow Rate and Droplet size from Agricultural Nozzles

The conventional technique for controlling the flow rate of liquid from an agricultural nozzle has been to vary the pressure of the liquid supply. This may not be the most ideal way of altering the flow rate for three major reasons: 1) the system response can be slow (less than 1Hz), 2) excessive pressure may be required to satisfy the flow rate required (flow is proportional to square root of pressure), and 3) changes in pressure is likely to affect nozzle performance: specifically the droplet size spectrum and the spray pattern. Recent, improved nozzle designs have reduced the influence of nozzle operating pressure on droplet size and spray pattern, but changing flow rate without effecting pressure and pattern when working with ordinary hydraulic nozzles still remains to be a problem.

A flow control system developed by Giles and Camino (1990) allows independent control of the liquid flow rate and droplet size spectrum emitted from hydraulic nozzles. They employed principles of Pulse-Width Modulation (PWM) to accomplish their objectives. PWM has been typically used in industrial control systems using electrical, hydraulic or pneumatic actuators. Recently, a commercial company (Capstan Ag System, Topeka, Kansas, USA) has successfully applied this technology to control flow rate from agricultural nozzles. With this system (called SYNCHRO), nozzle flow is modulated by intermittent operation of an electrically-actuated solenoid valve coupled to the inlet of the conventional spray nozzle. Controlling the relative proportion of time during which the valve is open or closed controls the volumetric flow rate from the nozzle. Wires along the boom connected to the SYNCHRO controller activate individual valves pulsing in the range of 1-25 cycles per second. Fluid flow is determined by the length of time valves remain open- their "duty cycle". System response time is relatively fast, providing a flow rate change of 5 to 1 in 0.3 second. Droplet size remains the same as the flow rate is reduced from 5 to 1. Changes in flow rate are made from an electronic controller that sends a signal to control the valve. Flow is adjusted at the nozzle by the solenoid valve. The valves attach to the standard nozzle diaphragm check valve port, replacing the diaphragm and cap. SYNCHRO is designed as a retrofit kit to work with conventional boom-type spraying systems equipment with an ordinary (commonly used)

electronic controller.

In addition to changing flow rate and droplet size, SYNCHRO also allows the operator of a sprayer to rotate the nozzles up to 90 degrees around its vertical axis when concentration of spray material in a narrow band is desired.

Giles and Ben-Salem (1992) and Giles (1996) confirmed experimentally the independence between PWM-controlled nozzle flow rate and resulting spray droplet size. As shown in Figure 6, the volume median diameter (VMD) from an 8004 spray nozzle (80° spray angle with 1.51 L/min nominal flow rate at 280 kPa) at various operating pressures remained relatively constant within each operating pressure. PWM at 10 Hz and duty cycles from 10% to 100% were used to modulate flow while liquid was supplied to the valve at 70, 140, 280, 420, and 700 kPa. Using the data in Figure 6, one

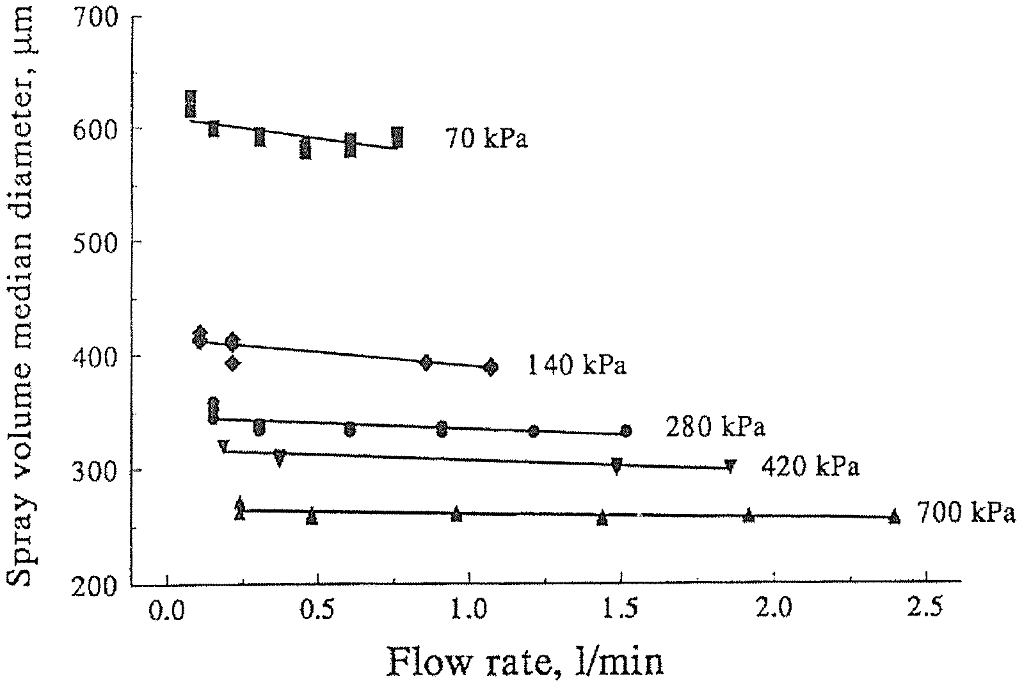

Figure 6. SYNCHRO system performance at various pressures (8004 nozzle)

can develop a flow rate and droplet size control envelope using the boundary points of the response lines. It is suggested by the manufacturers of SYNCHRO that one can choose any combination of flow rate and droplet size which falls within this envelope by exciting the valve/nozzle device with a corresponding PWM duty cycle and liquid supply pressure. Similar flow rate/droplet size envelopes has been established for other nozzles with different nominal flow rates.

Uniformity of deposition with SYNCHRO was a concern since PWM technique results in intermittent flow from nozzles. To avoid this concern, the control system was

designed such that adjacent valves received PWM signals approximately 180° out of phase. Giles (1996) compared uniformity of deposition from SYNCHRO system to that from a commercial, pressure-based, rate controller. Both control systems were mounted on the same sprayer and calibrated to maintain an application rate of 150 L/ha. Deposition was measured by placing 4 m strips of water sensitive paper perpendicular and parallel to the direction of vehicle travel. Results from nozzles with 80° fan pattern showed variation to be significantly greater from the PWM technique in some cases. However, when tests were conducted with 110° fan pattern nozzles, the resulting deposition from the SYNCHRO system was significantly more uniform.

This technology has just been introduced, and has not been tested in the field adequately. The cost of the system may be a deterrent to its adoption by the farmers. However, as the variable rate application of agricultural chemicals gains more acceptance; as more pesticide labels start displaying recommended droplet sizes; and as spray drift continues to be a major health and safety problem, systems like SYNCHRO are likely to gain more popularity among applicators of pesticides in the future

E. The "CP" Nozzles

CP nozzles (manufactured by CP Products, Mesa, AZ) are designed to bring convenience to the commercial applicators who change nozzle size as they move from one field to another. The atomizer (Figure 7) consists of an orifice plate with a range of

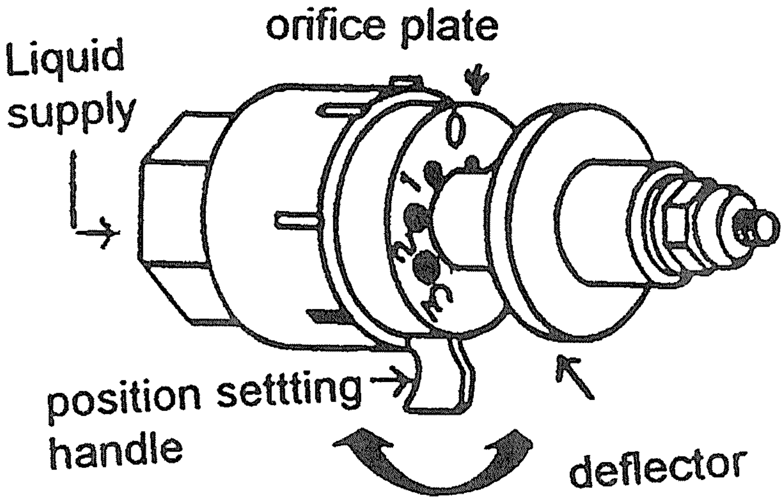

Figure 7. CP nozzle

hole sizes (orifices), and a curved, circular deflection plate which provides a spray pattern similar to the pattern produced by flood-fan nozzles. By simply dialing in the desired orifice, the applicator can choose the flow rate desired without changing the tips. Depending on the orifice selected, this nozzle can provide application rates ranging from 10 to 40 L/min. For best results, it is recommended that this nozzle body should be mounted on the boom at an angle of 0 to 30 degrees above the horizontal, pointed opposite to the travel direction.

F. Tower Orchard Sprayers

Several sprayer manufacturers now supply modification kits, or new airblast orchard sprayers with vertical duct (tower) air-distribution systems. Most of these sprayers redirect air produced by the axial fan to a vertical duct (metal or plastic) where it may exit from a continuous vertical slot or an air jet outlet at the top of the tower. Tower attachments to sprayers redirect the vertical component of the sprayer air jet to the horizontal direction. Thus spray is released much closer to the top of the tree canopy than with a conventional axial-fan sprayer. Also by directing the air jet horizontally through the tree canopy, less spray should be lost to drift through the top of the orchard. Commercial versions of cross-flow fan sprayers are available in both Europe and USA. Fans on these sprayers are usually about 1.5 m long and 0.4 m in diameter. The air jet from this type of fan is similar to an ideal plane jet; it is about 0.15 m wide and 1.5 m vertically. Several fans are stacked one above the other and produce a continuous jet directed horizontally toward the tree. Because these jets do not spread radially as distance for the jet outlet increases, the jet tends to maintain its centerline velocity better than axial-fan jets. Thus cross-flow fan sprayer jets will transport spray greater distances horizontally than axial-fan jets. They also should achieve more uniform spray coverage, because the spray droplets are released closer to all parts of the tree canopy. The air jets are directed horizontally (sometimes the top jet is even directed a few degrees downward), therefore, less spray is blown out of the top of the orchard canopy as drift, compared to a conventional axial-fan sprayer.

G. Spray control using canopy sensing

The canopy of tree fruit crops often is not uniform. There are often gaps in the canopy near the tops of trees. Sometimes trees die and are replaced with much smaller trees, which increases the irregularity of the canopy. As a result, we lose pesticide that is sprayed through these gaps in the tree canopy. During the last decade, several companies have developed canopy sensors that are aligned with a nozzle or group of nozzles. If these sensors detect canopy, the sensor(s) are turned on, if no canopy is detected, the nozzle(s) are turned off. Several types of sensors have been used, including infrared, ultrasonic, and imaging systems that detect the color of chlorophyll in leaves. In 1992, a company in Florida decided to use a technology developed for the Department of Defense called "Range Image Sensors with Automatic Target Recognition" (RISATR). This system detects three dimensional images of targets on the ground using laser lights. The Florida company used RISATR to detect tree canopies in an orchard. The sensor system takes tree measurements every 2.5 cm when traveling at a speed of 4 km/hr, and provides a map of the shape of the tree just before the sprayer is in line with the tree. This sensor, called TREESENSE, provides more precision than other sensors because more samples are taken. It can detect targets at a greater distance (30 m compared to 10 m or ultrasonic sensors), and there is no travel speed limit (8 km/hr for ultrasonic system). TREESENSE requires only 1 sensor, whereas an ultrasonic system may require 10 to 20 per sprayer.

H. Use of biological controls

Several types of biological pest control agents are currently being used. These control agents include nematodes, insect pathogens, predator insects, pheromones, etc. New application techniques are required to apply these materials that are often living creatures.

Many fruit and vegetable growers in western states such as California, Washington, and Oregon are greatly interested in biological pest control. The idea of applying beneficial insects to destroy pest insects is not new. But there are not many effective, economical ways to distribute these beneficial insects to the target plant. In some cases, they were applied as part of a dry product which was difficult to keep on the plant surface long enough to be effective. Even beneficial insects applied with a liquid carrier would often not stay where they were deposited. In many cases, beneficial insect eggs would fall to the ground because they did not adhere to the target foliage. Also, these beneficial insect eggs or larvae, or even bacteria such as Bt, would not survive the high pressures in the sprayer system. A carrier substance for delicate biological agents has been developed using 100 percent food grade materials. This carrier suspends the beneficial insect eggs for even distribution on the plants, and adheres them to the target leaves where they hatch. These materials are applied with a low-pressure applicator that does not damage the eggs in the storage tank or in the atomizer. Tractor mounted units for orchards and a back-pack sprayer for ornamentals are available.

Other research on specialty applicators for other biological materials is cited in the article by Fox et al. (1998) included in these proceedings.

CONCLUSIONS

Yield and crop quality depend on effective application of herbicides, insecticides, fungicides, fertilizers, growth regulators, etc. Applying an insufficient amount of chemical wastes time, money, and materials; an overdose adds to the cost, may damage the crop, and cause environmental pollution. Traditional methods and equipment used for application of pesticides are highly inefficient. Significant developments have been made in the last 5 years in design of application equipment. Unfortunately some of these innovations have not yet been widely accepted by the pesticide applicators mainly because of high initial costs of the equipment, and lack of knowledge about these technologies on the part of applicators. Although there are still many unanswered questions, pesticide application can become a more efficient operation as we continue to educate the applicators and as the new, more efficient application equipment becomes available to applicators at an affordable price.

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美國農藥施噴之最新發展

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摘要

新型農藥是更有效的且需更精確的應用。發展新方法與設備來達到農藥使用之最大效率，使對使用者與環境之潛在危險減至最小之研究於大學、政府部門及工業界持續進行中。本文在噴霧應用技術研究及減少噴霧飄移並改進應用效率之最新發展方面概述主要之發展。這些發展包括產生較大霧粒之低飄移噴嘴、空氣引入、靜電及氣流噴霧化等。其他所討論之飄移減少技術包括氣流輔助式噴霧器、噴桿屏蔽及隧道式噴霧器。支援精耕農業技術包括變率噴霧器、全球定位系統及地理資訊系統技術、封閉式農藥傳輸系統及流量控制系統。新的果園噴霧技術包括塔型噴霧器及作物株叢感測技術。生物害蟲防制藥劑常需特別輸送系統以防損毀散佈於植物株叢上活的有機體。

前言

全世界所製造之農藥約三分之一於美國賣出。近年來美國農藥使用已相當穩定，約五億公斤之有效成份。由於作物生產成本及環境污染增加之考量，必需精確與小心施用農藥。

農藥施用為一種複雜作業，需較其他作物生產有更多之技巧、管理及精度。其包括有很多精密步驟，如農藥於槽中之均勻混合、從噴霧設備至目的地之有效輸送、農藥於目的物之保留及農藥有效成份由植物、昆蟲之吸收力。

液體農藥施用之最無效狀況為霧粒從噴嘴至目標之傳輸。研究顯示經常是僅有一部份之化學藥劑確實達到目的物並對所希望之生物效應有所貢獻。噴霧之一部份從未接觸目的物。這些噴霧飄移問題為一種嚴重的健康與安全問題。近年來噴霧飄移之減少已為全球大學與研究機構中許多研究計畫之焦點，因為減少噴霧飄移不僅可增進應用效率且可減少環境污染。

目的

本文之目的為提供在美國噴霧應用技巧與發展上主要發展之概述。這包括促進減少噴霧飄移與增進施用效率。雖然在噴霧技術上重要發展已於全球開展，以下所提供之概述包括在美國進行之主要發展。

I. 減少噴霧飄移之研究與設備發展

雖然完全消除噴霧飄移十分困難，但如增加飄移危險之因素可以改變或消除，則其數量可大大減少。特別是施用者不能控制之氣候狀況-- 風，扮演飄移

產生及移動之一重要角色。影響飄移之最重要應用因素為噴霧霧粒之大小。沈澱於目標物上之小霧粒提供較佳之覆蓋且經常導致增加農業害蟲之防治結果。然而小霧粒易飄移。

當使用傳統噴霧設備時，由直徑小於 100 µm 組成之全部噴霧霧粒體積雖相當小，但即使是如此少量，有時可能引起嚴重的健康問題並損壞附近田地之作物。

一些近期發展已朝向修改現有設備來減少飄移可能，以增進更多有效小霧粒之沈澱效率。一般而言，這些已可藉使用氣流輔助技術或一些屏蔽或遮掩物來克服產生飄移之氣流與當噴霧時噴嘴附近發生之亂流來完成。

噴嘴分類系統

美國農業工程師學會最近已接受一定義多種噴嘴產生霧粒大小分類之新標準。定義之霧粒大小分類包括非常細、細、中、粗、甚粗與極粗。

在約公元 2000 年時，農藥製造商將開始在農藥標籤上指定每一種農藥使用之最小噴嘴種類。在一些狀況下，標籤將指定特定風速狀況下不同的噴嘴，亦即如風速高於 20 km/hr 時，必須用粗型噴嘴，但如風速低於 10 km/hr，可使用中型噴嘴。

噴嘴製造商目錄將包含有關每一噴嘴於每一作業壓力下霧粒大小分類之資訊。

A) 新噴霧器/噴嘴

"低飄移" 噴嘴

大多數農用噴嘴製造商最近提議設計製造在相同流速及作業壓力下比標準平扇型 (SFF) 噴嘴有較大霧粒之「低飄移」噴嘴。此可組合式地藉於傳統排出孔前面加入一前孔至噴嘴尖端來完成。標準平扇型噴嘴尖端有一直孔，其可攜帶液體從噴桿至尖端。在新式「低飄移」之噴嘴 (圖 1) 中，液體進入一小孔並流入一用機器崁入噴嘴體之小室內。液體從此室流入一短通路並由排出孔流出。 此前孔減少液體速度並形成減少飄移之大霧粒。

Turbo Drop 噴嘴 (圖 2) 設計為當減少細粒霧粒百分比時產生大霧粒。藉置於上截面底端之陶瓷孔板控制液體流速。據製造商言，Turbo Drop 噴嘴頗能減少小霧粒之飄移。

空氣引入式 (AI) 噴嘴

大多數農用噴嘴製造商已發展並上市空氣引入式噴嘴。這些噴嘴全部使用與 Turbo Drop 噴嘴相同之原理。這些噴嘴有一前孔，然後從一空氣進口部分有

一漸縮截面，空氣噴霧混合後經由噴嘴尖端離開噴嘴前之混合室。這些噴嘴可減少可能飄移霧粒(小於 150 μm)之百分比並可能減少飄移問題。

靜電式噴霧器

小霧粒靜電式充電被視為增加小霧粒沈積效率及減少飄移的一種方式。雖然靜電噴霧於工業應用之研究已進行超過 50 年，但直至 1970 年代初期，充電式噴霧之應用尚未延伸至農業。如今在美國有二家公司 (ESP 及 ESS) 製造並上市噴霧器，此噴霧器可將靜電式充電之霧粒放電。最近所有之靜電式噴霧器採用感應充電技術。

氣流霧化器

氣流霧化器可僅使用空氣壓力或同時使用空氣與液體壓力來霧化並攜帶噴霧溶液至目標。現今有二種氣流霧化器於美國使用，其一為「AirJet」(圖 3)，另一為「Shaer Guard Plus」（圖 4）。

B) 氣流輔助式噴霧

在過去數年間，於農藥應用上氣流輔助桿式噴霧器之使用已有增加。此增加使用背後之主要因素乃施噴區域外小霧粒飄移之影響。

商用氣輔噴霧器之氣流輔助原理類似。一充氣空氣管置於傳統液壓噴桿後方。空氣藉離心式風扇驅入管中 。空氣在與垂直方向呈一小角度(此角度於一些機器上可調整），沿空氣管底部穿過約 5cm 直徑孔離開空氣管。噴嘴於空氣管前端產生霧粒並在高速空氣離開空氣管時進入並被攜帶至目的物。如需要的話，空氣流速可改變或停止。

雖然氣流輔助技術已證實能有效地減少飄移增進沈積，現今使用此技術之商品化施藥設備尚未見使用者廣泛採用，主要是因為設備花費相當昂貴。

C) 噴霧器噴桿屏蔽

1996 年 Ozkan 等人於 10 m 長 1.5 m 寬 1.0 m 高之風洞中進行試驗，研究不同型式噴桿屏蔽對噴霧飄移之影響。採用一半置於風洞內 3 × 3 m 之噴霧型態桌，並分析具與不具屏蔽噴霧之沈積型態，以評估九種屏蔽設計 (圖 5) 之效果。於試驗中採用具 110° 噴霧角及 0.6 L/min 公稱流量(在 0.3Mpa 壓力下) 之平扇形噴嘴。

所有實驗之屏蔽性能於二種噴霧壓力(0.15 與 0.3 MPa)與在風洞中二種空氣流速 (2.75 與 4.80 m/s) 下被評估。另外，也進行一組無屏蔽相同壓力與空氣流速下之試驗。得到以下結論：

1. 所有九種屏蔽有效地減少噴霧飄移。 即使最無效之屏蔽設計(由多孔材

料製成之屏蔽)，在地面之噴霧沈積亦增進13%。雙薄金屬片屏蔽(屏蔽2)導致最佳性能；與無屏蔽之相同噴嘴比較其增進59%之噴霧沈積。

2. 即使在使用具較高流速噴嘴之情形下，屏蔽依舊有效(產生較少小霧粒)。

3. 如適合的話，選擇具較大公稱流量之噴嘴在減少飄移之效能上如同建構一圍繞噴桿且昂貴的屏蔽。

D. 隧道式噴霧器

商業用隧道式噴霧器在歐洲與美國是可用的。這些噴霧器有一金屬片或塑膠覆蓋之框架。其典型地有4或5米長，有足夠寬及高來跨越一列之矮樹或葡萄數。

II. 其他於農藥施噴技術之主要發展

A. 農藥變率施用技術

精耕農業技術之主要工作包括1)在田地上指定位置之驗證(經度，緯度，高度)；2) 蒐集指定位置相關土壤物理特性、土壤營養成份、農業害蟲侵襲面積、作物產量等資訊；3) 使用電腦軟硬體儲存這些資訊； 4) 處理及分析這些資料；及5) 依據儲存於電腦內之資料，使用適當儀器做實際農藥之施用。

B. 使用全球定位系統之標誌系統

目前泡沫或機械標誌系統被用以確認噴霧器一次路徑之覆蓋面積。現今此項工作可藉使用全球定位系統或調頻收音機訊號系統來完成。

C. 密閉式農藥傳輸系統

在農藥混合及輸送中主要之水污染源為潑出。雖然密閉式農藥傳輸系統在美國是不必需的，但為了減少作業者曝露於農藥下及環境污染之危險，這些系統將成為現在大多數製造噴霧器之標準設備。

D. "SYNCHRO" – 一種流量及霧粒大小之數位控制系統

控制農用噴嘴中液體流量之傳統技術為改變液體供應壓力。基於下列三點主要理由，此法並非最理想改變流量之方法：1) 系統反應可能會慢 (小於1Hz)，2)可能需過度之壓力以滿足所需之流量(流量與壓力平方根成正比)， 3) 壓力改變多半影響噴嘴性能。

由Giles及Camino(1990) 利用脈衝寬度調變(PWM)原理發展出一種流量控

制系統允許獨立控制由液壓噴嘴射出之液體流量及霧粒大小。最近美國一商業公司已成功地應用此技術控制農用噴嘴之流速。此一系統 (稱為 SYNCHRO)中，噴嘴流量藉間歇操作聯結至傳統噴嘴入口之電動螺線管閥來調變。在閥開或關中間控制時間之相對比例來控制噴嘴體積流量。圖 6 中顯示，一編號 8004 噴嘴(於 280kPa 壓力下，具 1.51 L/min 公稱流量與 80° 噴霧角) 在每一不同之作業壓力下體積中點直徑(VMD)保持相當一致。

E. "CP"式噴嘴

CP 式噴嘴設計帶給商業施噴人員相當便利，當他們從一地移至另一地時可改變噴嘴大小。噴霧器（圖 7）由不同孔徑範圍之孔板與一彎曲圓形區偏向板組成。視所選之孔而定，此噴嘴之流量範圍為 10-40 公升/分。

F. 塔式果園噴霧器

大部份此類噴霧器將軸向風扇產生之空氣更改方向至一垂直導管，其可由塔頂之連續式垂直槽或空氣射出口流出。在這些商用噴霧器上之風扇直徑約 0.4m，長度約 1.5 m。

G. 使用作物株叢感測之噴霧控制

在靠近樹頂之株叢常有間隙。噴霧穿越樹木株叢間隙造成農藥損失之結果。在近十年中很多公司開發出由一個或一組噴嘴排列成之作物株叢感測器。如這些感測器偵測到作物株叢，則開啟感測器，如無偵測到作物株叢，則關閉噴嘴。多種型式之感測器已被使用，包括紅外線、超音波、及偵測樹葉中葉綠素顏色之影像系統 。

H. 使用生物防制

很多型式之生物病蟲害防治藥劑正使用中。這些防治藥劑包括有線蟲、蟲病原、捕食昆蟲等。為了使用這些經常是活的生物材料，新應用技術是必須的。

應用益蟲摧毀害蟲之觀念並不新。但並沒有很多有效且經濟之方法將益蟲散佈至目標植物上。在某些狀況下，它們難以有效長期黏附於植物上。在大多數狀況下益蟲卵將因無法黏附至目標物葉上而掉落地面。這些益蟲卵或幼蟲或細菌如 Bt 也無法於高壓噴霧系統中生存。使用 100%食用級材料作為精緻生物藥劑媒介物已發展出。這種媒介物將益蟲卵懸浮於其中用以分佈於植物上，黏附於目標物葉上益蟲卵將被孵化。這些材料在噴霧器或貯存槽中被低壓應用設備施用並不會損害蟲卵。

結論

產量及作物品質視滅草劑、殺蟲劑、殺真菌劑、肥料、生長調節物質等之有效應用而定。施用不足量之農藥浪費時間、金錢與材料；而過量使用增加成本，可能損害作物且引起環境污染。使用傳統方法與設備施用農藥是非常無效率的。近五年來農藥施噴設備之設計方面已有重要的發展。但不幸的是由於設備之高成本及一部份應用者欠缺相關技術之知識，這些新發明的一部份尚未為農藥施用者廣泛接受。雖然仍有一些未獲解答之問題，當我們持續教育施噴者，且新而更有效率之施用設備可以更低價位提供施噴者時，農藥施噴可變成一更有效率之作業。

REVIEW OF PESTICIDE APPLICATION RESEARCH IN OHIO AND THE U.S.

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ABSTRACT

This review of pesticide application research will be discussed in two sections. First, a summary of research in the U.S. will be given, followed by a discussion of research in Ohio. There are several universities, federal laboratories and industrial locations in the U.S. where research on pesticide application is being conducted. We will review only selected research projects here, mostly related to spray drift, precision farming, whitefly control, and bio-control methods. The major effort on application technology research in Ohio is conducted in three research units. All authors are associated with the Laboratory for Pest Control Application Technology (LPCAT) with at least adjunct appointments, and work cooperatively on many projects. For discussion purposes, projects will be divided into three groups, based on the major source of funding. The groups are: LPCAT, FABE Department, and USDA-ARS, ATRU. Research projects now active and/or active in the recent past are discussed. Approximately 30 research projects in Ohio are summarized and published references listed.

INTRODUCTION

Research programs in the U.S. have a tendency to follow trends, i.e., certain research areas become popular and many scientists conduct research programs in this area. Currently there is much interest in precision farming. This leads to several research topics in pesticide application. In precision farming, it is useful to control the sprayer output, and to change spray application rates from on part of the field to another. Therefore many research projects are aimed at this problem, for example, in-line injection, on-off flow controllers, weed/crop sensing, etc. Drift of pesticide is another popular area of research. Many studies are being conducted on low drift nozzles, drift retardant adjuvants, and drift modeling. Sometimes grower problems trigger research effort. A few years ago some species of sweet potato white fly developed a resistance to the commonly used pesticide. This insect caused much damage to many crops

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throughout the southern and western U.S., and many research projects were initiated to control this pest. Whiteflies tend to live on the bottom of leaves at the bottom part of the canopy; research was conducted on canopy penetration and spray deposit patterns on the bottom of leaves. Using reduced rates of pesticide is a continuing research goal, so many studies on deposit and spray technology to improve deposit uniformity is conducted on many crops in all parts of the U.S.

SUMMARY OF RESEARCH PROJECTS

IN THE U.S., EXCEPT OHIO

Precision farming:

In addition to studies in Ohio, several other groups are conducting research related to precision farming. We have included some IPM/ICM techniques in this section because precision farming inherently integrates many IPM/ICM practices in a controlled way. Systems for in-line injection of pesticide usually include controls that are useful for controlling the application rate of sprayers. Tompkins et al.(1990), Rockwell and Ayers (1996), Qui et al. (1998) have studied the problems associated with inline injection. Giles and Ben-Salem (1992) and Giles (1997) developed a solenoid-controlled nozzle for adjusting flow rate over a wider range than is possible with pressure changes, without changing the spray pattern or droplet size. This spray system is now being commercially manufactured in the U.S. This system can also be used to spray larger droplet sizes by operating larger nozzles with more 'off-time'. Vetter (1995, 1996) tested the effectiveness of GDPS for guidance of ground and aerial spraying. Chaisattapagon and Zhang (1991), Franz et al. (1995), Simonton and Graham (1996) and others have attempted to identify plant types by using image analysis. Such a system would allow more precise control of herbicide sprays. . Giles and Slaughter (1997) used an imaging system to control the width of a spray band used for spraying a row of small plants. Meyer et al. (1998) developed a system to identify plants from soil and to discriminate among several weeds. Ngouajio et al. (1998) developed a system to estimate the area covered by weed and crop canopies and bare soil. An imaging system captured frames and the image system selected 1000 pixels for classification by an operator. The system was quite accurate in field studies with several types of weeds at several densities but not as accurate with small corn plants.

Some commercial sprayer systems for pre-emerge herbicide application identify plants growing in bare soil by using detectors for reflected light. Some systems are passive, i.e., the light source is ambient light, whereas other systems include a beam of light source of known wavelength and intensity. Hanks (1995) found the sprayer with the light source detected plants more reliably than the passive-detector sprayer, due to soil background changes (wetness, organic matter content, soil type, etc.) and angle and intensity of the sunlight.

Parish et al. (1995) studied the effect of tillage practices for weed control to minimize pesticide use.

Spray drift

The Spray Drift Task Force (SDTF) is a association of 36 agricultural chemical

manufacturers who combined their efforts to plan and conduct drift measurements from spraying with aircraft (both fixed- and rotary-wing), ground boom, air-blast, and chemigation spray applications. They also conducted extensive measurement of physical properties of a wide range of agricultural spray tank mixtures, measured evaporation of spray droplets, and the droplet size spectrum from a wide range of agricultural nozzles under actual field conditions (simulated wind and travel speeds, etc.) These studies were intended to convince the USEPA that spray drift is controlled by many factors, but that the active ingredient is not an important factor. This means that the companies would not have to conduct drift studies for every chemical. The SDTF and EPA are also developing computer models to predict downwind deposits for each spray system – aerial, ground boom, and air-blast. Many papers and presentations have resulted from this massive effort. A few examples are: Teske et al. (1998), Huddleston et al. (1995), Hewitt et al. (1998)

Bui et al. (1998) report on an on-going study to identify suitable samplers for measuring airborne spray. Several other groups have considered the effect of nozzle type on swath deposit (Smith (1992).

Whitefly control

Coates (1996) and Coates and Palumbo (1997) tested several sprayer treatments for control of whitefly in cotton and cantaloupes. They found that air-assisted and electro-static sprayers deposited more spray on the underside of leaves and produced somewhat better control of whitefly in the early season. However, when the canopy was mature, there was no significant difference among sprayer treatments.

Bio-control methods

Delwiche et al. (1998) developed a labor saving method of applying pheromones to orchard trees that released the active ingredient over a longer time period than standard delivery systems. Morisawa and Giles (1995) measured damage to insect larvae exposed to handling techniques required for possible mechanical delivery systems.

SUMMARY OF RESEARCH PROJECTS IN OHIO

The most important element in any research program is the people involved. Therefore we begin the discussion of research in Ohio by listing scientists associated with each major research team.

Laboratory for Pest Control Application Technology (LPCAT)

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Ross D. Brazee, Research Leader, *Robert D. Fox*, Agricultural Engineer, *Richard C. Derksen*, Agricultural Engineer, *Charles A. Krause*, Plant Pathologist, and *Michael Klein*, Entomologist.

LPCAT PROJECTS

Bioavailability

The research focus is on the interaction of application and biological effect. This includes the process whereby an applied toxin is encountered by the target organism, transferred to the target, arrives at the active sight, and produces a biological result. Some parts of this process are unique to individual crop protection agents (e.g. herbicides, insecticides) while other aspects are more universal. For pesticides which are sprayed, the spray must impact and be retained by the target surface (plant or soil). The retained pesticide must be encountered by the target organism. Contact is through movement and feeding for insects. For soil applied herbicides contact is through plant growth. Uptake of pesticide is through a series of events which are affected by plant and insect cuticular microstructure, pesticide formulation and adjuvants, target metabolism, application method, and behavior. Reliable information on the effects of these variables does not exist, and there is no general body of theory to aid in predicting their effects. As a result many of the questions asked in scientific articles 50 years ago are the same ones being asked today. Advances in other fields (mathematics, computer science, chemistry, etc.) continue to provide solutions to intractable problems in understanding this complex process which is fundamental to understanding and manipulating bioavailability. LPCAT as a multidisciplinary team has played a key role in applying these innovations to understanding this process. This work has recently been facilitated through a three year EPA grant for examining the dose transfer process in biopesticides. References: Hall (1991c), Hall et al. (1996a,b) Hall (1997a), Hall (1997), Wolf et al. (1997)

Deposit structure and efficacy

This project has developed the use of mixture models for examining the relationship between deposit structure (deposit size, deposit number and a.i. per deposit) and biological effect. These efforts have included the development of bioassays (cabbage looper on insecticide treated cabbage, and glyphosate treated velvetleaf), and the development of a computer simulation. The computer model allows rapid evaluation of a large number of "experiments" while the bioassays provide a biological foundation. The Pesticide Dose Simulator (PDS) model can be used to explore the effects of deposit structure on efficacy. Mixture design models have led to several non-intuitive insights into the dose transfer process which clear up several inconsistencies in the literature - such as smaller droplets providing better efficacy in the lab, but CDA sprayers (which produce smaller droplets) requiring similar application rates in the field. Basically: 1) the chance of an insect dying from a pesticide application is never less than the probability of contacting the toxin; 2) uniform deposit structures result in lower insecticide efficacy for mobile chewing insects because they do not acquire a large

enough dose rapidly enough for the toxin to overcome insect growth. The former has promoted the notion that uniform applications are "good" while the latter has forced increased application rates to overcome the disadvantage of a uniform application. References: Adams and Hall (1990), Royalty et al. (1990), Adams et al. (1990b,1992), Thacker and Hall (1991), Thacker et al. (1992), Cooper and Hall (1993), Hall et al. (1993b), Head et al. (1995), Downer et al. (1997), Hoy et al. (1998)

Spray Atomization and Patternation

The Aerometrics Phase Doppler Particle Analyzer is being used to obtain droplet size spectra data of pesticide and additives. An Image Analyzer (IA) is used to size pesticide deposits on target surfaces, e.g. water sensitive paper. Water sensitive spray cards which capture droplets and allow for size measurements by the IA are extensively used in the field. A unique spray simulation lab is used to monitor spray patterns and >capture efficiencies of various plant canopies. In the past four years, atomization studies have included: effect of drift retardants on droplet spectra; effect of shearing polymers on spectra; effect of surfactants on spectra using several nozzle types; effect of adjuvants on spectra of commercial pesticide formulations in combination with several adjuvants; factors affecting spectra when spraying Bt; effect of Bivert on spectra; effect of temperature on spectra for formulations, spectra of rainfall simulator, etc. References: Chapple et al. (1992,1993,1995), Downer et al. (1993,1995)

Drift and Targeting

Pesticide drift studies have traditionally used a variety of collectors. Associated protocols on drift and eco-toxicological effects are being developed in conjunction with orchard drift experiments with collaborators in USDA. A wind tunnel capture efficiency model is being used to develop droplet capture efficiency data on target (plant) and non-target species (windbreaks).

References: Downer et al. (1996) ,Hall and Fox (1996), Reed et al. (1993)

Worker Exposure Studies

Health risks to pesticide applicators are being scrutinized more closely than ever before. Although the available data from epidemiological studies concerning pesticide use and certain associated disorders are practically non-existent, federal and state agencies are mandating this research be initiated Current worker exposure studies revolve around (1) a US-EPA grant to LPCAT on validating passive dosimeters, and (2) a NIOSH grant on "Risks to Farm Families" to OSU's Department of Preventive Medicine, with LPCAT as principle collaborator on the chemical exposure risk phase. Numerous grant inquiries are underway involving neuro-behavioral responses of workers, neural network modelling of toxins and the PI's involvement in developing an American Chemical Society symposium on pesticide safety (in '97). Pesticide risk mitigation related to mixtures of pesticides. Insecticides, herbicides, fungicides, adjuvants, and fertilizers may be combined in a single spray application. Testing individual pesticides is not relevant to human health risk assessment because pesticides are not encountered as isolated compounds. References: Reed et al. (1990b), Kirchner et al. (1996a,b), Wolf et al. (1997)

Pesticide Risk Benefit Analyses

A pesticide cost-benefit assessment model was delivered to all US State Pesticide Coordinators in 1995. Analyzing risks and benefits in a useful assessment/prediction scheme will require additional information on actual environmental hazards which remains a major effort at LPCAT. Pesticide policy issues (PI focus) are critical if pest control agents are to continue as effective tools of world agriculture. References: Hall and Lemon (1990), Lemon et al. (1992), Hall (1996)

Modelling

The LPCAT pesticide dose simulator (PDS) model was developed to simulate diamond back moth larvae feeding on Bt (*Bacillus thuringiensis*) treated cabbage leaves. It provides a fundamental capability for examining the effects of deposit structure on efficacy. Further development has increased the generality of the model for examining different formulations and AIs. The LPCAT evaporation model combined with other physic-chemical measurements allows a greater level of inquiry into pesticide characteristics, and optimizing toxin presentation to target pests. References: Hall et al. (1995)

FABE RESEARCH PROJECTS

Effect of drift retardant chemicals on spray drift, droplet size and spray pattern

Specific objectives of this study were to determine the effects of various drift retardant chemicals (Direct, Driftgard, Formula 358, Nalco-trol, and Target) on droplet size, spray pattern, and spray drift reduction. The results of this study indicated that, at recommended rates, Nalco-trol provided the largest increase in volume median diameters of the sprays followed by Direct, Target, Driftgard, and Formula 358. In general all drift retardants created patterns with greater volume toward the center than that of water only. Cumulative deposits beyond 1.6 ft downwind increased for all drift retardants when the wind velocity was increased from 4.5 to 9 mile/h. In general, the effectiveness of drift retardant mixtures for minimizing spray deposit distances was closely related to droplet size increase. References: Ozkan et al. (1993a,b, 1994)

Effect of nozzle wear on spray pattern and droplet size

The effects of nozzle wear on spray patterns delivered by fan pattern nozzles made from different materials were investigated. An automated computerized weighing system was used to rapidly evaluate the spray deposit distribution. The results indicate that there was some difference between the spray deposit distributions of new and worn fan nozzles. The width of the spray pattern remained nearly constant but the worn nozzles delivered greater volumes of liquid in the centers of the patterns. The effects of nozzle wear on droplet size spectrums delivered by fan pattern nozzles made from different materials were investigated. Flow rates of the nozzles tested were 0.2, 0.4, 0.6 and 0.8 gal/min, and the materials were brass, nylon, plastic, stainless steel and hardened stainless steel. Although the worn nozzles produced slightly larger $D_{V0.5}$ values, generally there was little difference in droplet size distributions between new and worn

nozzles with flow rates smaller than 0.6 gal/min. The difference, however, was greater for the nozzles with flow rates of 0.6 and 0.8 gal/min. A standard procedure for measuring nozzle wear was develop and approved by ASAE as Standard S471. References: Ozkan et al. (1991, 1992a,b), Ozkan and Reichard (1991,1993), Reichard (1991a,b), Reichard et al. (1991), Zhu et al. (1995a,b)

A survey on attitudes of applicators toward pesticide waste reduction

As part of the ongoing pesticide education programs in Ohio, a survey was conducted in eighteen counties to learn more about current pesticide application and disposal practices. The survey also provided information related to applicators' attitudes toward reducing pesticide waste. Survey results based on 1380 responses indicate over two-thirds of the respondents calibrate their sprayers at least once a year. Approximately 10% never calibrate. Over 90% of the respondents always rinsed empty pesticide containers. However, only 71% followed acceptable rinsing procedures. About 3% indicated they do not rinse containers at all. Burning was the number one method of pesticide container disposal used by applicators. Although over two-thirds of the applicators feel well-informed about pesticide container disposal practices, the number of improper disposal methods identified by the respondents indicate that educational programs are needed to help applicators choose the most environmentally sound disposal practice. In general, the pesticide applicators expressed a positive attitude toward reducing pesticide waste. References: Ozkan (1992b)

Subsurface injection of turfgrass insecticides

Surface application of insecticides on turfgrass for control of many subsurface grubs is not very efficient. It can be potentially hazardous to people, pets and other animals exposed to the insecticides. To reduce this danger, three injection systems were developed to place insecticides below the turf surface and into the main grub activity zone. Results indicate that insecticides can be successfully injected with little damage to the turf. Analyses of surface residues after injection of two common turfgrass insecticides showed significant reductions ranging from 38 percent to 95 percent over the amount remaining from spraying on the surface. Grub control using two of the three injection methods was equal to or better than that achieved with the conventional surface application method. A third injection method using a rolling point applicator was not evaluated for grub control because the preliminary data showed little dispersion of insecticide from the point of injection and a low probability of achieving effective control. References: Ozkan et al. (1990a,b)

Deposition efficiency of air-assisted, charged sprays in a wind tunnel

Small spray droplets which rely primarily on electrostatic and gravitational forces for transportation and deposition are highly susceptible to drift. Also, spray penetration into dense plant canopies is often inadequate. Spray deposits of air assisted charged sprays, with volume median diameter of 92 μm, were collected in a wind tunnel with wind velocities up to 11 mile/h. The results indicated that an air jet with 24.6 mile/h downward air velocity at the point spray was entrained, greatly increased the amount of spray deposited in the target area and also improved penetration of the spray

downward into the canopy and reduced drift. References:Almekinders et al. (1992,1993a,b), Khdair et al. (1994)

Computer simulation of spray drift from field sprayers

A computer program was used to determine the effects of several variables on drift distances of individual spray droplets. Variables were initial droplet size, velocity and height of discharge, wind velocity and turbulence intensity, relative humidity, and volatility of the liquid. Drift distances of water droplets as large as 200 μm diameter were influenced by initial droplet velocity and height of discharge. Experimental data from tests in a wind tunnel verified the accuracy of the computer program in predicting drift distances of water droplets. A computer program was developed to calculate mean drift distance for individual spray droplets. This program accepts input parameters, then interpolates among a data base of results from flow simulation trials to obtain drift distancd for the input conditions. References: Reichard (1992a,b), Reichard et al. (1994), Reichard and Zhu (1995), Zhu et al. (1994, 1995c)

An automated computerized spray pattern analysis system

Most of the patternators used currently to investigate nozzle spray pattern characteristics are of the manual type using collection cylinders. These patternators are susceptible to human error during recording and analyzing data. This process is also labor intensive and time consuming. Results of a survey conducted indicate that with manual patternators it takes an average of 35 minutes to collect and analyze pattern data for one nozzle. The automated single collection unit system described in this article provides a more efficient means of data collection and analysis. On an equivalent per cylinder basis, the time for data collection takes about 0.5 seconds. It also takes only about a minute to complete a test with this system. The automated system was found to be relatively accurate compared to manual systems. References: Ozkan and Ackerman (1992)

Use of shields to reduce drift

The effects of partially covering spray booms with six different mechanical shields on deposition distances of spray droplets were simulated by using a computational fluid dynamic software, Fluent®. The same shields were mounted in a wind tunnel and drift distances of uniform-sized droplets in a 13.4 mile/hr air stream were measured. Use of solid bluff-plate shields inevitably resulted in a low velocity zone immediately behind the shield or within the shielded area. As compared with conventional straight-down spraying, all shields simulated, except ones, reduced drift potential. The double foil shield was confirmed to be the best design for mechanical shields in this study. The optimal operating parameters of pneumatic shielded spraying, obtained by a multifactor analysis of variance, were jet velocity of 90 mile/h, jet flow rate of 3600 ft^3/min, and jet angle of 15 degrees. Mean deposition distances from simulation and experimental distances to centers of masses agreed well for only 2 of 6 mechanical shield designs tested. Effect of shield-induced vibration and improper size ratio of shields to the wind tunnel may be reasons for this inconsistency. References: Ozkan et al. (1997a,b), Tsay (1997)

Measuring mixing in an agrochemical sprayer tank

Effectiveness of hydraulic jet agitation systems of agricultural chemical sprayers were investigated by measuring the concentration of a kaolin clay/water mixture in the line to the boom. A surface scatter type turbidimeter was employed to evaluate the concentration of simulated wettable powder pesticides during an application. An agitation index, called "AGEF", was defined to help evaluate the effectiveness of each agitation system separately regardless of tank size and shape. AGEF was based on three measured mixing criteria: particle deposit remaining on bottom of tank following application, the coefficient of variation of mixture concentration in the line to the boom, and ratio of maximum deviation of mixture concentration at the tank outlet to the mean concentration measured during the application. Experiments were conducted on several sprayer tanks of different capacities and agitator type. The results showed AGEF was sensitive enough to enable reasonable comparisons and this method can be used to standardize minimum requirements of a hydraulic jet agitation system. System pressure was the most important factor affecting agitation effectiveness through its direct influence on jet velocity. Single-phase solutions to Fluent computer models agreed well with these results. However, solving three dimensional, turbulent, multiphase flows (Eulerian granular model) was not feasible using personal computers because computation times would be several months. References: Ackerman et al. (1993), Ucar (1997).

Lag times and uniformity of inline injection of spray materials

Injection sprayers can eliminate some problems associated with conventional sprayers, however, injection sprayers have inherent problems of lag time and mixture uniformity at nozzles. A turntable sampling system was designed to measure uniformity of the mixture in the spray boom and the lag time required for the desired mixture concentration to be sprayed from nozzles at a range of boom lengths. A computer controlled system allowed the operator to collect samples easily at any nozzle while the simulated sprayer underwent accelerations or decelerations. Three water-soluble and one non-water-soluble liquids (water, Prime Oil, Prime Oil II and Silicon Oil) with viscosities that ranged from 0.9 to 97.7 centipoise were used as the simulated pesticides. Uniformity of the mixtures with the simulated pesticides in two boom sizes (3/8 and 3/4 in. diameters) and uniformity across the spray patterns of nozzles at different positions on the boom were investigated. Lag times to the expected rates of application were also measured. Viscosity of water-soluble or non-water-soluble liquid slightly influenced the mean flow rate from the metering pump, but did not influence the lag time. Simulated pesticides with the highest viscosities were very difficult to mix with water, and it was necessary to use a spiral mixer. Increasing the number of active nozzles on the spray boom reduced the variation of the mixture uniformity in the spray boom. Lag time to the desired rate of application at the nozzle at the end of the boom was greatly reduced by reducing the boom diameter, but this lag time was not reduced substantially by reducing the number of active nozzles on the boom. References: Zhu, et al. (1998a,b,c)

USDA-ARS ATRU RESEARCH PROJECTS

Orchard air jet velocity profiles and model

The mathematical model for ideal, plane jets was modified to include the effect of radial expansion as the air jet moved away from a circular jet outlet. This model was found to have an improved fit to the maximum velocity across a jet as distance from the jet increased, as compared to the plane jet model previously used. Jet profiles were measured for two axial fan sprayers and agreed well with model predictions using the radial jet model. Centerline velocities in an air jet produced by a cross-flow fan sprayer were measured and agreed well with predicted values computed using a plane jet model. For jets that have equal air power at the jet outlet, models for ideal jets predict that axial jet velocities from jets with greater air volume and lower maximum air velocities will decrease much less as distance from the outlet increases, compared to jets with high velocity and lower air volume. Measured air velocities for sprayers passing an array of hot-film anemometers on towers in the open and in apple trees found that maximum jet velocities produced by moving sprayers was much less than velocities measured for the same jets when stationary. A model of the deflection of an air jet by travel speed or cross wind was developed. Jet deflection and velocity profiles predicted by for the deflected jet were similar to velocities measured for a model jet operated in a wind tunnel. References: Brazee et al. (1981), Fox et al. (1985, 1992b)

Drift from orchard sprayers

Ground-level and airborne spray samples were collected downwind of apple orchard in a series of drift experiments over the past 8 years. Convention axial fan and air-curtain/cross-flow fan sprayers were used to successively spray the downwind, edge row of trees each year. With an available crew of about 12 people, about 5 replications could be conducted in one day. Due to row planting directions, measurement of drift is only possible when the wind is approximately perpendicular to the row direction. In our experience, only about 1 to 2 days per month had a suitable wind direction for drift experiments. We usually set up the major collection and meteorological towers for about 2 months per year, set up temporary collectors and prepared for drift trials about 4 to 5 times per year, and actually sprayed about 2 days per year. Fluorescent tracers were used. Rigid plastic sheets and, later, plastic tape was used to collect ground deposits. Airborne spray was collected on passive collectors such as string, plastic tape and, recently on nylon screen. High volume air samplers were also as an active collector of airborne spray. Different fluorescent tracers were used in each sprayer and collectors were changed after both sprayer completed each pass. A total of about 50 spray passes have been made during the 7 years when drift experiments were conducted, thus a range of wind conditions have been encountered. Three orchard sites have been used to provide a range of canopy sizes and shapes. References: Fox et al. (1990a,b, 1991b, 1993a,b,c, 1994b, 1997), Fox (1993), Reichard et al. (1992a,b, 1994), Derksen and Breth (1994), Reichard and Zhu (1995,1996), Derksen and Gray (1995), Perez et al. (1995), Coffman and Derksen (1997)

Greenhouse spraying

Electron beam analysis (EBA) was used to measure chlorothalonil smoke particles on artificial target surfaces in greenhouses. Particles averaging less than 3.0 μm in diameter and as small as 0.4 μm were found to vary significantly in number with location within a poinsettia canopy and with distance from the source of the smoke.

Particles did not vary significantly in size either within the canopy or with distance from the source. No measurable residue was found when the greenhouse was not tightly sealed. EBA proved to be a viable method of investigating fungicide smoke deposition and can provide precise information about the environmental fate of pesticides related to application technology. References: Tappan et al. (1995), Derksen and Sanderson (1995), Obendorf et al. (1995)

Spraying of nursery crops

Spray penetration and off-target spray drift from a conventional, air-assist, axial fan sprayer and a high-clearance, boom-type sprayer were investigated in honey locust or canadian hemlock located in two different production nurseries. Another study in a production nursery compared spray coverage on sheared red maple from an axial fan sprayer with a cross-flow fan sprayer. Aqueous tracer solutions of either $Ca(NO_3)_2$ foliar fertilizer, $Cu(OH)_2$ fungicide, or food coloring were used in the experiments. Spray distribution and drift were assessed via residues collected on foliage, electron microscope stubs, vertical and ground-level profile tapes, clamped leaves, and high-volume air samplers. Electron beam analysis (EBA) was used to assay residues on stubs, leaves and needles placed and/or collected at several locations and elevations in the canopy. Profile-tape samples were evaluated with a laboratory spray deposit analyzer using a conductivity detector. Spray coverage for the hemlock and locust treatments was incomplete throughout either canopy as assessed by either method. Experimental results indicated that ground-level spray deposits and airborne drift varied with the spray method used. Spray deposits on red maples (about 3.5 m tall) were measured using blue food coloring and $Cu(OH)_2$ fungicide. Colorimetry and EBA were used to measure deposits on leaves clamped at 12 locations (3 elevations, 4 quadrants) in each of three trees. The cross-flow fan sprayer produced more uniform distributions throughout the tree, but the axial-fan sprayer produced greater deposits at almost all locations than the cross-flow fan sprayer. References: Krause et al. (1997), Zhu et al. (1997b)

Effectiveness of low turbo teejet and TurboDrop nozzles in drift reduction

Small-to-medium size droplets are desirable when applying insecticides and fungicides because they provide better penetration into the canopy and better coverage. However, small droplets can drift long distances. Almost all major agricultural nozzle manufacturers have recently introduced "low-drift" nozzles which claim to be effective in reducing spray drift. The objective of this study was to determine effectiveness of two "low-drift" nozzles (Turbo TeeJet® and TurboDrop®) in reducing drift. This was accomplished by measuring droplet sizes, and deposition distances of droplets in a wind tunnel (11 mile/h) using the low-drift nozzles and comparing the data from these measurements with those obtained from a standard flat-fan nozzle. The low-drift nozzles produced fewer drift prone droplets and less downwind deposits than the standard flat-fan nozzle (XR). Droplet size measurements taken along the long axis of the spray patterns showed less variation in droplet size for the XR and Turbo TeeJet (TT) nozzles than for the TurboDrop (TD) nozzles. The TD nozzles produced lower downwind deposits than TT nozzles operated at similar pressures (40 psi); however, a larger orifice TT nozzle operated at a lower pressure (25 psi) performed similar to the TD nozzle operated at 40 psi. Plugging the air intake hole on the TurboDrop nozzle

increased nozzle output, decreased VMD, and slightly increased the percent of spray volume in drift prone droplets and downwind deposits. References: Derksen et al. (1997)

Shear effects on drift retardants

Some research has indicated that certain drift retardants may degrade due to the shearing action of recirculation through a agricultural sprayer pump. A laboratory system was developed to simulate shear on spray mixtures of water and drift retardants due to recirculation of mixtures in sprayer tanks. Three drift retardants were evaluated in both a Myers A36 orchard, airblast sprayer and the laboratory system. Droplet size distributions of sprayed samples from the sprayer and the laboratory system were measured with an Aerometric Phase/Doppler Particle Analyzer. Droplet size distributions of sprayed samples with drift retardants sheared with the laboratory system had similar trends to those of samples sheared with the airblast sprayer as the number of recirculations increased. In a further study, ten polymers which are primary active ingredients in commercial drift retardants were tested. Samples of the solutions were taken after 0, 1.0, 2.3, 3.9, 6.4, and 11.4 passes through a centrifugal pump system. Apparent extensional viscosity (AEV) and screen factor (SF) were measured for all samples. After being sheared by more than 4 passes through the pump, both non-ionic and anionic polymer-solutions at 100 ppm did not increase $D_{V.5}$ much over values for water alone. Both apparent extensional viscosity ($R^2 = 0.8$) and screen factor ($R^2 = 0.7$) were well correlated with spray $D_{V.5}$. . These results show that some drift retardants may fail to maintain their ability to increase spray drop sizes after they have bypassed several times in an agricultural sprayer. References: Fox et al. (1996), Reichard and Zhu (1996), Reichard et al. (1996), Zhu et al. (1997a)

High speed image capture

High speed movies (6000 frames/s) were made of droplets impacting on leaf surfaces. Many plant leaves have a surface wax structure that reflects spray droplets on initial impact. The movies enabled observing the number of droplets that were reflected and the height of rebound, but measurements of rebound characteristics were not easy to make. A high speed video system was developed to capture several video frames in succession. The video speed was only from 15 to 150 fields/s, however, by using high speed strobe lighting as a shutter, interesting images of droplet rebound paths could be obtained. The video system, used in conjunction with two different mono-disperse droplet generators, quantified droplet impaction and any consequent reflection. Three techniques were used for assessing the deformation at impaction of a single droplet on an artificial surface, and reflection of both single droplets and droplets in a spray cloud, from a variety of plant surfaces. Determination of droplet in-flight diameter, dimensions of impacting droplets, droplet velocity prior to and immediately after impaction, and reflection height and number were all possible depending upon the technique selected. References: Reichard et al. (1986), Fox et al. (1992a)

Droplet impaction and reflection

Droplet reflection depends, to some extent, on the speed of the impacting droplet and droplet size, but the main factor in determining reflection is the micro-structure of the

leaf surface. Some plants, such as cabbage, wheat, and rice reflect nearly all spray droplets that impact on the surface. Large droplets (500 μm diameter) tend to be reflected more than small droplets (100 μm diameter), but we have recorded water droplets less than 70 μm that reflect from cabbage leaves. Typical droplets impacting on reflective leaves remain on the leaf surface less than 1 ms. While the droplet is on the leaf, it greatly increases its surface area by distorting into a pseudo-torus shape, then reduces surface area by drawing back into a spherical shape before springing from the leaf surface. Some adjuvants, such as surfactants tend to reduce reflection. In fact, if high concentration of some surfactants are used, refection can be eliminated. Most surfactants must move to the liquid interface to become active. With the large changes in droplet surface area during the impaction process, the diffusion rate of typical surfactants is too slow to reduce surface tension in the one millisecond available. References: Bukovac and Reichard (1990), Reichard (1990), Bukovac et al. (1993,1995), Brazee et al. (1994,1997), Reichard et al. (1998)

Dynamic surface tension

Several physical properties of the droplet liquid, such as surface tension and extensional viscosity, may affect reflective potential of spray droplet from plant leaves. Equilibrium surface tension, a commonly measured liquid property, is not a reliable indicator of reflection tendency. However, dynamic surface tension has been found to be strongly related to droplet reflection. An oscillating jet method was developed enabling measurement of dynamic surface tension at a range of short surface ages, even as short as 1 ms. Bohr's equation and Bechtel's inverse method were used to calculate surface tension from measurements of the jet waveforms. Some surfactants are unable to reduce surface tension rapidly at short air-liquid interface ages typical of droplet impaction processes. Hence, they may be unable to effectively limit reflection and improve retention. A thin-film diffusion model was developed which can be used to calculate dynamic surface tension at a range of surface ages, given liquid properties, surfactant diffusivity, apparent interfacial film thickness, and surfactant concentration. Correlating measured dynamic surface tension data with the diffusion model provides estimates of apparent film thickness and diffusion of surfactant/water mixtures. These activity properties are useful in understanding surfactant effects on high shear rate physical processes such as droplet atomization and leaf-surface impact, where short surface ages are critical. Most agricultural sprays are mixtures of materials, not true solutions, and as such their surface tensions change with surface age. Measuring surface tensions at short surface times may also be valuable in predicting droplet size spectra from atomization processes, because these processes are usually completed in less than 3 ms. Brazee et al. (1991), Bechtel et al. (1995), Reichard et al. (1997)

Image analysis

Computer imaging equipment and image processing software has been used by ATRU staff to measure quality aspects of spray applications. Measurements of feature density, size, and target coverage have been used to compare the performance of different application techniques. Evaluations have been made using artificial targets such as oil and water sensitive paper and natural targets such as plant leaves. Different

image processing algorithms have been used to evaluate images depending on the target, tracer, and droplet size characteristics. Morphological image processing techniques proved most useful when evaluating parameters of features produced by water-soluble tracers. Recent acquisition of an epi-fluorescence microscope with a high intensity, UV light source will improve our ability to evaluate coverage produced by different application methodologies through use of fluorescent tracers and other materials that naturally fluoresce. This equipment will also permit study of the interaction between the spray quality and pest damage on leave surfaces as well as the effect of spray formulations on plant material. Natural fluorescence of plant pathogens and leaf structures will also be studied to determine if these may aid in evaluating the application process, pest management, or crop production. References: Salyani and Fox (1994,1997), Derksen and Jiang (1995), Jiang and Derksen (1995)

Japanese beetle

Adult and immature Japanese beetles (JB) are serious pests of turfgrass, flowers, fruit crops and ornamentals. The larvae, white grubs, develop in the soil in the grass root zone. Control of these grubs is difficult because a significant portion of pesticides applied to the turf can become bound by organic matter in the thatch and never reach the feeding sites. Several entomopathogenic bacteria, fungi, and nematodes have been tested for grub control. Although several commercial biological products are available, results of their use has been inconsistent. A survey of northern Ohio golf course turf found about 20% of the sites had detectable entomopathogenic nematode (EN) populations. However, only about 15% of these EN provided more than 75% control of grubs in laboratory tests. Selected isolates of Ohio EN performed as well in field tests as did commercially available nematodes. Improved application methods may enhance EN control of JB larvae. In addition, EN performance may be increased when used with other control agents. An insecticide, imidacloprid, was shown not only to be non-toxic to EN, but to have a synergistic effect against masked chafer and JB larvae when both control agents were used simultaneously. In a new approach to pathogen application, autodissemination, beetles are lured to a trap where they become coated with a fungal pathogen and subsequently transfer the fungus to larval feeding sites. References: Mannion et al. (1996), Grundler and Klein (1997), Klein and Moyseenko (1997)

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俄亥俄州與美國農藥施噴研究之回顧

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摘要

農藥施噴研究將在下兩段討論。首先、討論在美國的研究，接著討論俄亥俄州的研究。在美國有一些大學，聯邦實驗室與產業界一直進行農藥施噴的研究。在此，吾人僅選擇一些研究計劃加以敘述，大部分是有關噴藥飄移（spray drift）、精耕農業（precision farming）、粉虱控制（whitefly control）與生物控制（bio-control）方法。在俄亥俄州有三個研究單位致力於施噴技術的研究。本文所有作者皆與害蟲防制施噴技術實驗室（LPCAT-Laboratory for Pest Control Application Technology）相關，至少是兼職成員，並且在許多計畫中共同合作。為便於討論，計畫因財源不同而分成三大部分，即為 LPCAT、FABE 學系與 USDA-ARS ATRU。大約有 30 個俄亥俄州的計畫被摘錄下來，所發行之文獻也被列出。

前言

在美國的研究計劃有一種追隨趨勢的傾向，即有一些領域受到歡迎，就會有許多研究者加入此研究領域，目前較有興趣的是精耕農業，這導致一些研究題目集中在農藥施噴。精耕農業對控制噴霧器輸出是很有效的，其可改變田間各部份之農藥施用率。因此許多研究計劃集中在此問題上，例如農藥線上注入、流量開關控制、雜草/作物辨識等。農藥的飄移是另一個很受歡迎的研究領域，許多研究著重於低飄移噴嘴、抗飄移添加劑（drift retardant adjuvants），與飄移模式。有時作物栽培者之問題亦會引起研究者的努力，若干年前，有一種甘薯的粉虱對常用農藥產生抗藥性，這種昆蟲導致美國南部與西部很多作物之嚴重損失，於是許多研究計劃就開始涉入來控制這種害蟲。粉虱通常生存於作物株叢底部的葉背部份，研究皆集中於霧粒穿入株叢及於葉背沉積之模態。如何降低使用農藥一直是各研究的目標，所以在美國各州有許多有關沉積與噴藥技術之研究被進行以改進農藥沉積的一致性。

美國除了俄亥俄州外相關研究之摘要

精耕農業

在此吾人介紹一種 IPM/ICM 技術，因為精耕農業本身就整合了許多 IPM/ICM 技術於一控制方式中。如農業的線上噴射（in-line injection），通常包含了噴射器之流率控制。其中參考文獻中有許多學者，致力於線上噴射研究（如 Tompkins，Rockwell，Qui 等），而 Giles Ben-Salem 發展出一種比利用壓力變化更可應用於廣大範圍的螺旋形控制噴嘴，此噴嘴是調整流率，並不改變噴霧方式或霧粒大小。這種噴霧來說在美國已經商學製造了！

Vetter（1995.1996）利用 GDPS 的有效性做為地面與空中噴霧的導引。

亦有些研究者（如 Chaisattapagon，Franz，Simonton 等）利用影像分析來辨識 植物型態。Gile Slaughter 與（1997）使用影像系統於一列小型植物上，來控制噴霧帶的寬度。

Meyer（1998）也利用影像技術從土壤中來辨別植物且可辨別出各種雜草。

Ngouajio（1998）利用影像系統來預估雜草、作物樹叢及裸露土壤的面積。

一些在預露除草劑應用的商業噴霧器系統可經由光反射偵測器來辨識於裸露土壤上作物生長狀況。發現有光源噴霧器來辨識作物會比被動式偵測噴霧器來的可靠，因為土壤背景的變化與角度及日光的強度不同。Parish（1995）致力研究中耕時利用最小量農藥使用來控制雜草

噴霧飄移（Spray drift）

SDTF（Spray Drift Task Force）是一個由 36 位農業化學製造商組成的學會，其結合力量致力於利用飛行器、鼓風機與化學噴霧應用之噴霧飄移量測技術。

他們也從事於廣大範圍農業噴藥桶混合的物理性質量測，噴霧霧粒蒸發量測即在實際田間狀況下，（模擬風速及行進速度）廣大範圍農用噴嘴的噴霧分佈之霧粒大小量測。

這些研究企圖說服 USEPA，說明噴霧飄移是由許多因子來控制的，噴藥配方有效成分不是主要因子。

SDTF 與 EPA 也研究對每一噴霧系統預估順風沈積附著的電腦模式。亦有一些學者研究各種噴嘴刑式（Suits 1992）

粉蝨控制

Coates 與 Palumbo 利用一些噴霧器來控制棉花與甜香瓜上的粉蝨。他們發現氣輔式（air-assisted）與靜電式（electro-static）噴霧器會在葉背有較多的沈積附著，如此在較早的季節裡，可有效來控制粉蝨、然而當樹叢再成長時，就較不

可行了！

生物控制方法

Delwiche（1998）發展出一種利用費落蒙於果樹上的省力方法。

Morisawa 與 Giles（1995）量測用機械分送系統處理已暴露昆蟲時的損失。

俄亥俄州研究計劃摘要

再俄亥俄州有三個單位一些學者再研究此方面的技術如：

Laboratory for Pest Control Application Technology (LPCAT)

Frank R. Hall, Head of LPCAT and Professor, *Roger A. Downer*, Research Associate, *Timothy A. Ebert*, Research Associate, and *Venkat Pedibhotla*, Research Associate, Dept. of Entomology, OARDC/OSU, Wooster, OH

Food, Agricultural, and Biological Engineering (FABE), The Ohio State University, Columbus, OH

H. Erdal Ozkan, Professor and *Tim Stombaugh*, Assistant Professor.

USDA-ARS Application Technology Research Unit (ATRU), located at OARDC, Wooster, OH.

Ross D. Brazee, Research Leader, *Robert D. Fox*, Agricultural Engineer, *Richard C. Derksen*, Agricultural Engineer, *Charles A. Krause*, Plant Pathologist, and *Michael Klein*, Entomologist.

LPCAT 研究計劃

生物有效性（Bioavailability）

這些研究注重於應用性與生物影響的交互作用。這些包含了應用毒素於標的有機體，轉移到目標物到達活動性視界，然後產生一生物結果之過程。此過程的一些部分是唯一作為單獨作物保護媒介物（如除草劑、殺蟲劑。）

對噴灑農藥而言，此農藥必會填上並殘留目標物表面（植物或土壤）。殘留農藥必會影響到目標物之有機體。其接觸是由昆蟲的移動與餵食才有作用，對土壤應用殺蟲劑的接觸是經由植物的生長。農藥的吸收是經由一連串的事件的影響如植物與昆蟲外表皮的微構造、農藥配方與添加劑、目標物的新陳代謝作用方法，應用與行為等。

對這些變數沒有較可靠的資料。也沒有一般的理論來預測它們的影響。其他較先進的領域（如數字、電腦、化學等）、連續提供在了解此複雜過程處理問題的解答，此複雜過程即為了解與操作此生物有效性。

LPCAT 為一多種學科的團隊，在應用這些創作來了解此過程扮演了很重要的角色。此工作經由一來自 EPA 財務支援的三年計畫來檢查這些生物農藥的依據過程。

沈積物結構與功效

此計畫是研究利用混合模式來調查沈積物結構（沈積物尺寸、沈積物數目）與生物效應關係。這些成果包括了生物測量的發展（如甘藍的殺蟲處理、甘藍銀紋夜蛾），與電腦模式。此電腦模式可提供一生物基礎生物測定大量實驗的快速評估。

農藥劑量（PDS-Pesticide Dose Simulator）模式可用來探究沈積物的結構功效性的影響。

混合設計模式影響到一些直覺觀察藥劑的過程、此能掃除以前文獻中的矛盾，例如在實驗室中小的霧粒可提供較好的功效，但在田間 CDA 噴霧器（可產生較小的霧粒）需要相似的應用率。基本上：1）從農藥施噴上害蟲死亡率從不會少於毒藥接觸的機率：2）均勻沈積結構會導致變動咀嚼昆蟲較低的殺蟲功效，因為它們不必快速的獲得大量毒藥劑量來克服昆蟲的生長。

噴霧自動化與樣式（Spray Automization and Patternation）

氣體相位都卜勒顆粒分析儀（Aerometrics Phase Doppler）是用來得到農藥與添加物的顆粒大小之光譜資料。而影像分析儀（IA-Image Analyzer）是用來估量在目標物表面之農藥顆粒大小的，如感水性紙。感水噴霧卡可擷取霧粒且可用 IA 在大規模田間利用來量測霧粒大小。唯一的噴霧模擬實驗是用來監測噴霧模式與擷取各種不同植物樹叢的效率。在過去四年來，自動化研究包括：飄移沈積物在顆粒光譜上的影響；剪力聚合體在光譜上的影響；使用不同噴嘴其噴灑面積在光譜上的影響；商業農藥配方混合各種添加物後視其添加物在光譜上的影響等。

飄移與標定（Drift and Targeting）

農藥飄移研究傳統上是使用各種不同的收集器，在飄移與生態毒物的效應聯合初步研究也是結合了 USDA 共同合作研究果園飄移之試驗、一風洞擷取效率模式是利用於目標物與非目標物上之霧粒擷取效應。

工作者暴露研究（Worker Exposure Studies）

農藥使用者的健康危機一直是研究者的重點。雖然考慮農藥使用與一些雜亂物之實際上在污染病學研究的有效數據上是不存在的。聯邦與州代表委託開始這些研究。目前工作暴露研究包含了（1）US-EPA 委洽 LPCAT 於消極的有效用量計之研究（2）NIOSH 委託 OSU 的預防醫學系做「農戶家庭危機」之研究，而 LPCAT 為在此化學暴露危機上的主要合作對象。很多的委託研究多在工作者的神經性行為、毒物的神經網路模式與在 1997 年，PI 介入在一美國化學協會上討論農藥安全。農藥危險的減緩與農藥的混合有關，殺蟲劑、除草劑、殺黴菌劑、添加物與肥料可能會在一噴藥應用混合應用。

農藥為害效率分析（Pestcide Risk Benefit Analyses）

農藥成本效率評估模式早在 1995 年美國農藥協會就已使用了。在一有用的評估/預測模式上分析危害與利益，需要一些實際環境為害的額外資料，而這一直是 LPCAT 努力的目標。

模式（Modeling ）

LPCAT 的農藥劑模擬器（PDS-pesticide dose simulator ）已被發展來模擬處理甘藍菜業以 Bt（Bacillus thuringiensis ）餵食菜蛾幼蟲的情況。它提供了檢查藥劑結構在功效上影響的基本能力。另外又增加了檢查不同的配方與 AIs 之通論模式。 LPCAT 的蒸發模式結合其他物理化學測量，可以提供探究農藥特性與在作物蟲害的最佳毒物代表更多的資料。

FABE 研究計劃

飄移沈積化學物質在噴霧飄移、霧粒大小與噴霧樣式的影響

此研究的特別目標為決定各種飄移沈積化學物質在霧粒大小、噴霧樣式與噴霧飄移減少上的影響。

這研究結果指出推薦 Nalco-trol 提供給由 Direct 、Target ，Driftgard 與配方 358 而成的噴霧體積中央直徑最大增加量。

一般而言，所有飄移沈積物會造成比水較大的向中心體積樣式。

當風速從 4.5 哩/小時增加至 9.0 哩/小時，對所有飄移沈積物而言，會在順風情況超過 1.68 英呎的連續沈積物。

一般而言，對最小噴霧沈積距離的飄移沈積混合有效性與增加霧粒大小有密切關係。

噴嘴磨損對噴霧樣式與霧粒大小的影響

噴嘴磨損對噴霧樣式的影響經由不同材料製成的風扇樣式噴嘴已做過研究。一種電腦自動稱重系統被用來快速預測噴霧沈積分佈。這結果指出新的、舊的風扇噴嘴所造成的噴霧沈積分佈是有一些差異的。基本上噴霧樣式的寬度是要保持定常數的，但是破舊的噴嘴會噴出的樣式中間有較多的液體。
不同材料的風扇噴嘴磨損對霧粒大小也有做過研究，用不同材料如銅，尼龍、塑膠、不銹鋼等與不同流率（0.2，0.4，0.6 與 0.8 加侖/分）來試驗。雖然破舊噴嘴會造成較大的 $D_{v0.5}$ 值，但一般而言，在流率小於 0.6 加侖/分 時，不論是新的或是舊的噴嘴在霧粒大小分佈上只有一點點的差異，但流率大於 0.6 與 0.8 加侖/分 時就有差異了！標準測量噴嘴磨損的程序可參閱 ASAE 標準 S471

使用者對農藥廢棄物減少的態度調查

在俄亥俄州進行的農藥教育計畫中，有做過 18 個郡的調查，來學習更多目前的農藥施噴與處理練習。此調查提供了農藥使用對減少農藥廢棄物的態度是如何，，此調查結果指出在 1380 個問卷中約有三分二的使用者，一年至少一次校正他們的噴霧器，約有 10% 的人從不校正，超過 90% 的農民會清洗空的農藥容器，然而、只有 71% 的人會照表使用手冊來清洗，亦有 3% 的人說他們從來不清洗的。

燃燒是使用者處理農藥容器的一種方法。一般言之、農藥使用者表現出對減少農藥廢棄物的觀點是正面的

草坪殺蟲劑的地下注射

在草坪表面用殺蟲劑，對控制地表的蠐螬是不太有效用的，它會造成人類，寵物其他動物暴露於殺蟲劑下之危險。為了減少這種危險，有三種注射系統可用來置放殺蟲劑於地表面下直接到主要蠐螬活動的區域。結果指出這殺蟲劑可以對草皮些微損失但可將殺蟲劑成功的注入地表下，在兩種常用草皮殺蟲劑注入後的表面殘留分析，顯示出比從表面噴射的殘留量有顯著的減少約 38% 到 95 % 之間。

使用此三種注射方法中的兩種來控制蠐螬會比傳統表面使用方法來的有效或更好。

在風洞中氣輔式，充電式 噴霧的沈積影響

主要靠靜電及重力來傳送及沈積的微小噴霧霧粒對飄移有多大的影響。而且比噴霧要穿透過濃密的樹叢是不太適用的。氣輔充式噴霧的沈積，在風速為

11 哩/時風洞中收集的體積平均直徑約有 92μm，此結果顯示出風速為 24.6 哩/小時時，點噴霧會被吸入，使目標物的面積有較多的沈積量，且能改善噴霧順風穿透到樹叢及減少飄移。

田間噴霧器噴霧飄移的電腦模擬

此電腦程式可用來決定各種變數在個別噴霧霧粒的飄移距離之影響。

這些變數最初的霧粒大小、速度與放出流量高度、風速及擾動強度、相對濕度與液體的揮發性。如 200μm 直徑大的水滴，飄移距離會受到最初的霧粒速度及放出流量高度。在風洞中測試的實驗數據證明了用電腦程式來預測水滴的飄移距離是很精準的。此電腦程式亦可用來計算各別噴霧霧粒的飄移距離。

一種自動計算噴霧樣式分析系統

大部分樣式計皆以人工方式使用收集圓柱管來研究噴嘴噴霧樣式特性，而這些樣式計在記錄與分析數據時易受人為誤差影響，此過程也很費工耗時。調查結果顯示利用此人工樣式計來收集與分析每一噴嘴的數據平均為 35 分，而此文所提的自動收集系統，收集與分析每一噴嘴約為 1 分種，即可完成測試。此自動系統與人工系統比較有可靠的精準度。

使用遮蔽減少飄移

使用六個不同的機械遮蔽於噴霧霧粒的沈積距離來覆蓋噴霧寬度的影嚮。可由電腦的流體動力軟體（如 Fluent）來模擬。不可避免的使用固定陡峭板遮蔽物，在遮蔽物後方或遮蔽區域內會同時導致低流速區域。在此研究中，雙鈍頭遮蔽式機械遮蔽物是最好的設計。

氣壓遮蔽噴霧的最佳操作參數，經由多因子變異數分析為 90 哩/小時噴射速度，3600 呎 ^{3}/分的噴射流，與 15 度的噴射角。遮蔽物對風洞的不適當尺寸比及遮蔽的振動會造成不一致性。

在農業化肥噴霧桶中心的混合量測

利用瓷土黏土/線上混合濃度的量測來探討農業化肥噴霧器的水力噴射攪動系統的有效性，一表面散佈型式的污濁計，被用來評估使用時模擬可加水粉狀農藥的濃度。一攪動指標（叫 AGEF）被定義不論量測桶大小與形狀，來評估各別攪動系統的有效性。 AGEF 是基於三個量測混合的準則：在使用時，顆粒會沈積於容器底部，由線上到橫桿之混合濃度變異係數在容器出口的混合濃度最大標準差與使用時平均濃度量測之比值。

噴霧材料線上噴射的時間延遲與均勻度

噴射噴霧器結合傳統噴霧器可消除一些問題，但噴射噴霧器本來就有在噴嘴上時間延遲與混合均勻度的問題。一旋轉台取樣系統是用來在噴物橫桿的混合濃度與在一橫桿 範圍從噴嘴噴出預期混合濃度的延遲時間，一電腦控制的系統被設計在一模擬噴霧器加速或減速下。使用者可以很容易收集每一噴嘴的樣本，三種水溶性與一種非水溶性的液體(water，prime Oil， prime Oil II 與 Silicon Oil)，且粘度在 0.9 到 97.7 cps(百分泊)的範圍內來模擬農藥。來研究在兩種尺寸（3/8 與 3/4 的直徑）下模擬農藥混合均勻度與在橫桿不同的沈積下，橫過噴嘴噴霧樣式的均勻度。水溶性與非水溶性液體的黏度會稍微影響從計量幫浦而來的平均流量率。但不會影響到延遲時間，高濃度的模擬農藥是很難與水混合的，且它需要使用到螺旋式混合器才行。

USDA-ARS ATRU 研究計劃

果園氣流噴射速度輪廓與模式

理想的數學模式是修改飛機噴射，包括從一個圓形噴射出口離開的噴氣流其徑向擴張的效應。此模式被用來改善配合，當距噴口距離增加時，橫過噴口最大的速度。利用兩個軸向風扇噴霧器與使用徑向噴射模式的預測來量測輪廓。量測橫流風扇噴霧器產生的氣流中心速，可以很適合的使用飛機噴射模式計算預測值，於是一流速或經過風中氣流偏離模式被發展出來，由偏離噴測預測出來的噴射偏離與速度輪廓和在風洞中由一噴射模型量測的速度很相似。

從果園噴射器的飄移

在過去 8 年來，於蘋果園中一連串的飄移試驗皆在收集順風下地表與空中的噴霧樣本。使用螢光追蹤器用硬的塑膠薄皮與後來的塑膠帶來收集地面沈積物，空中噴霧由被動式收集器來收集，如繩子、塑膠袋及尼龍屏風。高容器的空氣取樣器可作為空中噴霧的主動式收集器，7 年內大約有 50 種噴霧通過飄移試驗。

溫室噴霧

電子束分析（electron beam analysis-EBA ）是用在溫室中人工目標物表面的煙霧顆粒。平均直徑小於 3.0＊m 且如 0.4＊m 小的顆粒直徑會隨著猩猩木樹叢的數目與煙霧來源的距離而變化，EBA 是一種研究殺黴菌劑煙霧沈積物有效的方法，且能有關農藥環境與使用技術的一種精確的資訊。

種苗作物的噴霧

在兩個不同的種苗產業者的皂莢或加拿大鐵衫木研究從傳統氣輔式軸流風扇噴霧器和一高間距離桿式噴霧器的噴霧穿透性和目標外的噴霧飄移。另一種研究是在一種苗業者在一軸式風扇噴霧器與橫流風扇噴霧器在紅花械的噴霧覆蓋下之比較。噴霧分佈與飄移可經由葉子，電子顯微鏡殘片，垂直與水平輪廓式，夾葉與高容量空氣取樣器來收集殘留物，實驗結果顯示出地面噴霧沈積與空中飄移是隨著使用噴霧方法而異。在紅花槭（約 3.5m 高）上的噴霧沈積物是由藍色食品顏色與氫氧化銅黴菌量測而的。

低渦輪 T 型噴射與渦輪排放在飄移減少上的有效性

當使用殺蟲劑與殺黴菌時，小到中的尺寸霧粒最被期望的，因為他們提供了較好穿透過樹叢的特性與較好的覆蓋性。然而，小霧粒會飄移到較長的距離，幾乎大部份農業噴嘴製造商重點在低飄移的噴嘴，要求能有效的減少噴霧飄移。

此研究是使用低飄移噴嘴在風洞中心（11 哩/小時）量測霧粒大小及霧粒沈積距離，再與用一標準平扇噴嘴量測的數據比較，結果是低飄移噴嘴比標準平扇噴嘴有較少的飄移霧粒與較小的順風沈積。

抗飄移剪力效應

一些研究指出在經由農用噴霧原的再循環剪力作用會降低一些抗飄移，一實驗系統發展出一套用來模擬用噴霧器容器再循環混合產生的水與抗飄移物噴霧混合剪力效應。從噴霧器與實驗室噴霧樣本的霧粒大小分不由 APPDPA 量測，在另外的研究中，十個在商用的抗飄移物中，十種第一主要成分的聚合體被用來測試，這些結果皆顯示出在一農用噴霧器中一些抗飄移物在它們經由旁通管進出好幾次之後，就無法再維持能力來增加噴霧霧粒大小了。

高速影像擷取

高速影像（6000 畫面/秒）可應用於霧粒撞擊葉面時用。許多植物葉子表面結構有層腊，它會使再最初霧粒撞擊時產生反光，此畫面可以觀察到反光霧粒的數目與反彈的高度，但是反彈特性的量測，很不易做到。一個高速攝影系統來說可用來擷取些許連續攝影畫面。此攝影速度只在 15 到 150 畫面/秒，然而，使用高速連續曝光，可以抓到霧粒反彈的路徑畫面。

霧粒撞擊與反射

霧粒反射是依於撞擊霧粒的速度與霧粒大小,但主要決定反射的是葉子表面

的微結構。大的霧粒（500μm 直徑）比小霧粒（100μm 直徑）易於反射，但水的霧粒小於 70 仍會從甘藍菜反射。

動態表面張力

一些霧粒液體的物理性質，如表面張力與擴張性黏度可能會影響到從植物樹葉上的噴霧反射潛力。平衡的表面張力是熟知的液體性質量測，它無法成為反射趨勢的可靠指標，然而，動態表面張力與霧粒反射有關性，一種振動式噴射方法可用來測動態表面張力。

影像分析

ATRU 用電腦影像設備與影像處理軟體來量測噴霧應用的品質外觀。量測密度、大小與目標霧覆蓋情形，亦曾與不同使用技術的性能比較。不同的影像處理過程可用來評估影像與目標物、追蹤器及霧粒大小特性之相關性。當評估由水溶性追蹤器產生的外形參數，最有用的是使用形態學影像處理技術。

STUDIES OF SPRAY DROPLET-LEAF INTERACTIONS, INCLUDING EFFECTS OF SURFACTANTS

R.D. Fox, J.A. Cooper, and R.D. Brazee[1]

ABSTRACT

This article reviews recent advances in instrument development and in measuring techniques for agricultural spray droplets impacting on leaf and artificial surfaces. In most cases, spray droplets that reflect from a plant leaf fall to the ground and are not useful in pest control. Two types of uniform droplet generators are described along with high-speed cinema and video techniques for observing droplet/leaf interactions. Studies of reflection of droplets from leaf surfaces have found variation in reflection from leaves of the same plant. Reflection from some plant leaves change with the age of the leaf, or the growing conditions of the plant (in a greenhouse or outdoors). Droplet reflection from some other leaves vary with position on the leaf, that is, droplets may be reflected in greater numbers from near the tip of the leaf, compared to reflection near the center of the leaf. For these reasons, random leaf sampling techniques and replication of trials are very important. The oscillating jet method for measuring dynamic surface tension (DST) at short surface ages is discussed and some measured results for typical surfactants are presented. The system described here is the best system known for measuring these fluid properties. We have found DST to be correlated to droplet reflection. Thus a careful measure of DST of the spray mixture will provide insight into the likelihood of spray reflection of loss from the leaf surface. A DST model based on thin-film diffusion of surfactant molecules to the liquid/air interface was developed. Measured DST values over a range of surface ages was used to compute model constants for several surfactants.

Key words: reflection, impaction, uniform droplet generators, leaf surfaces, dynamic surface tension, oscillating jet.

INTRODUCTION

Application of foliar sprays is a complex process that includes such events as spray atomization, transport to the plant, impaction on plant surfaces, retention, and for systemic compounds, uptake by the plant. These processes all influence spray effectiveness. Droplet retention on a plant surface is only one stage in the application process, but it is critical since only retained spray is useful for crop protection while reflected spray can result in economic loss and contribute to environmental contamination.

Whether a droplet is retained or reflected by a plant surface is a function of

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the properties of the spray solution (surface tension and viscosity), spray pattern (droplet size and velocity), and the surface morphology (degree of pubescence, venation, fine-structure) and chemistry of surface functional groups of the target surface.

We propose that a better understanding of the role of spray additives, delivery systems and plant surfaces on spray efficacy can be achieved by improved measurement of droplet/leaf interaction. Reichard et al. (1986) and Reichard (1988) used high-speed motion photography and an analytical projector to observe and analyze the impaction and reflection of uniform-sized droplets from a spray cloud. Fox et al. (1992) and Reichard et al. (1998) described the use of a video motion analysis system in conjunction with two different droplet generators to observe droplet impaction.

Both droplet reflection from plant leaves and droplet atomization have short reaction times. Unpublished data from our laboratory show water forming spray droplets less than 3 ms after liquid exits a hydraulic nozzle orifice. Research shows spray droplets rebounding from leaves are generally in contact with the leaves less than 1 ms. A key physical property of liquid spray materials affecting these processes is surface tension. Our research shows equilibrium surface tension is not a good indicator of spray droplet's potential to be reflected from a leaf surface (Reichard, et al., 1997). Some surfactant solutions at concentrations above critical micelle concentration (CMC) are readily reflected from leaves, while higher concentrations of the surfactant suppress reflection completely. Thus, we developed a method for measuring dynamic surface tension (DST) at young surface ages (Reichard et al., 1997).

These studies all focus on the observation and quantifying of droplet impaction on leaf surfaces and measuring factors that effect this interaction. This paper will highlight some of the results from these and other papers resulting from this series of studies.

The objective of these studies was to develop techniques for examining and quantifying droplet impaction and reflection from leaf and artificial surfaces and measuring properties of spray adjuvants that may affect these droplet interactions.

Many of the techniques used in studying the droplet/leaf interface used a monosized droplet generator to aid in the examination of one particular aspect of the impaction process. By means of a specific type of droplet generator with image capture and analysis, several types of useful results were obtained.

EXPERIMENTAL EQUIPMENT

Spray application

Drop-on-demand generator

A drop-on-demand (DOD) generator, similar to that developed by Young (1979) was constructed to produce single, monosized droplets (Reichard, 1990) from 100 to 800 μm in diameter. All droplets had negligible velocity close to the orifice, thus in order to obtain a range of incoming velocities, vertical distance from the orifice to the target was adjusted. The advantages of this system are the ability to produce single droplets that can be precisely placed on different parts of the target surface, in a range of sizes commonly used in pesticide application. The system can

also be used to follow the trajectory (and thus calculate velocity) of incoming and reflecting droplets, and to determine reflection height. A disadvantage of the system is the inability to produce high velocity droplets. It can only be used to describe what happens to droplets traveling at terminal velocity or slower, for example, at some distance from the sprayer or after the initial droplet impaction.

Berglund-Liu generator

A Berglund-Liu* (BL) vibrating mono-disperse aerosol generator was modified to produce a stream of monosized droplets in the size range of 50 - 1500 m. A brass ring positioned approximately 1 cm below the orifice, at the point where the ligament first broke up into droplets, was operated at a DC voltage to induce droplet charges sufficient only to disperse the droplet stream, providing a spray cone covering approximately 1 cm^2 at the impaction site. An advantage of the BL over the DOD generator is the production of a spray cloud, compared to a single droplet, which more closely simulates hydraulic nozzle applications. The velocity of droplets produced by the BL generator is less than those used in the field. For example, a 250 µm droplet would typically have a velocity of 7.0 m/s when produced using the BL generator, compared to 20 m/s measured directly beneath the orifice of a typical hydraulic nozzle operated at 276 kPa. A further advantage is the ability to determine the proportion of incoming droplets reflected from a given surface, along with reflection height.

Motion analysis systems

High-speed photography

A 16mm, Hycam, high-speed motion picture camera was used to photograph the impaction of droplets. The Hycam camera is a rotating-prism type, capable of taking from 20 to 11,000 full frames/s. The camera is equipped with an event synchronizer that can be adjusted to trigger an event after the desired amount of film passes through the camera. Neon lamps in the camera were used to put 1000 marks/s on the film. The camera is designed for "C" mount lenses. When the lens cap to subject distance is 20 cm, the image on the file is about 0.7 times the object size. With this arrangement, the area photographed is about 11mm high and 15 mm wide. The depth of field is about 3 mm. Eastman Ektachrome No. 7250 with a 400 ASA rating for color temperature of 3200 K was used. Color film was faster than black and white film and provided better visual analysis of the finished film.

A framing rate of 6000 frames/s was selected because it allowed observers to follow the path of individual drops, yet illumination could be provided with standard tungsten halogen, slide projector lamps..

Video Motion Analysis System

The video motion analysis system (VMAS) used a monochrome video camera with a newvicon tube and a high resolution imaging board controlled by a menu driven motion analysis software package. This system provided basic video operations along with a wide selection of image examination, processing, and measurement operations (Fox, et al., 1992).

Moveable rulers could be drawn on the screen, and used to measure image features such as droplet diameters, height of reflection from the surface, and distance

between successive images of the same droplet.

Droplet Illumination

To illuminate an incoming droplet spray from the BL droplet generator, two stroboscopes were placed 0.05 m behind, and to either side of, the target leaf at approximately 45° angles to the longitudinal axis of the camera. The strobe was used at a flash rate higher than the field rate of the camera, so that several images of the same droplet were visible in each frame. Trajectories of reflected droplets were defined by the tracks of sequential images of each droplet (Fig. 1).

Figure 1. Reflection of water droplets from a cabbage leaf.

Oscillating jet method

Details of the oscillating jet (OJ) system used to measure DST are given by Reichard et al. (1997). An elliptical orifice was made from a hypodermic needle with a major axis approximately 2.5 times the length of the minor axis. A liquid jet issuing from the elliptical orifice assumed a standing waveform, characteristic of its physical properties, as it emerged from the orifice. A mirror, inclined at a 45° angle to the strobe, was used to obtain simultaneous front and side views of the OJ waveform. The imaging system provided resolution at 1976 x 1234 pixels per frame in interlaced mode, corresponding to

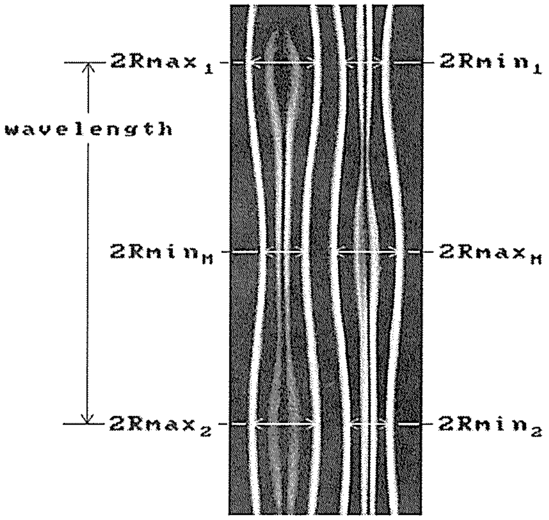

Figure 2. Digitized waveform of an oscillating jet, after edge enhancement, illustrating position of measured parameters.

horizontal and vertical scales of 2803 and 2393 pixels/cm respectively.

To calculate surface tension at a given surface age by two methods, seven measurements from the waveform were made (see Fig. 2). For examples shown here, surface tension was determined using four measurements on the left waveform in Fig. 2 and calculated by use of a modified Bohr equation (Thomas and Potter, 1975).

Solution surface tension at increasing surface ages was determined from waveform dimensions at increasing distances from the orifice until either the jet broke up due to capillary instability or oscillations were damped such that differences in amplitude were undetectable. To calculate surface age at which surface tension was measured, vertical distance from the orifice to $Rmin_M$ (the minimum between the two successive maxima used in calculation of surface tension) was divided by the jet axial velocity.

DST model

A DST model was developed by Brazee et al. (1994) using a thin-film diffusion theory. In the model, DST, σ(t), at surface age t is

$$\sigma(t) = \sigma_m + m_0 C_0 \left[1 - \frac{2}{\pi} \sum_{n=0}^{\infty} \frac{(-1)^n e^{-\pi^2 D (n+\frac{1}{2})^2 \frac{1}{a^2}}}{n + \frac{1}{2}} \right] \quad (1)$$

where m_o is a constant depending on solution equilibrium ST, surfactant concentration, C_o and surface tension of water σ_m ; *D* is surfactant diffusivity; and *a* is apparent interfacial film thickness. Model development was concurrent with DST studies using maximum bubble pressure and oscillating jet methods.

RESULTS AND DISCUSSION

Droplet impaction and reflection

The most important factor in determining whether droplets reflect from leaf surfaces is the leaf surface itself. Leaves with a well-defined wax structure , such as cabbage, usually provide ideal surfaces for droplet rebound. We have tried to make an artificial surface for droplet reflection experiments, but have not been successful. We tested 21 weeds for reflection of water droplets. About 1/3 had no reflected droplets, 1/3 had a few reflected droplets and 1/3 reflected almost all impacting droplets. Several major agricultural crops, such as wheat and rice, are highly reflective.

Within a plant species, other subtle factors can affect droplet reflection. We have found that small plants (4 leaf stage) grown in ideal conditions within greenhouses during the winter do not develop a typical wax layer, and as a result, often will not reflect water droplets, even though similar plants grown outdoors, or to a greater size, will reflect droplets.

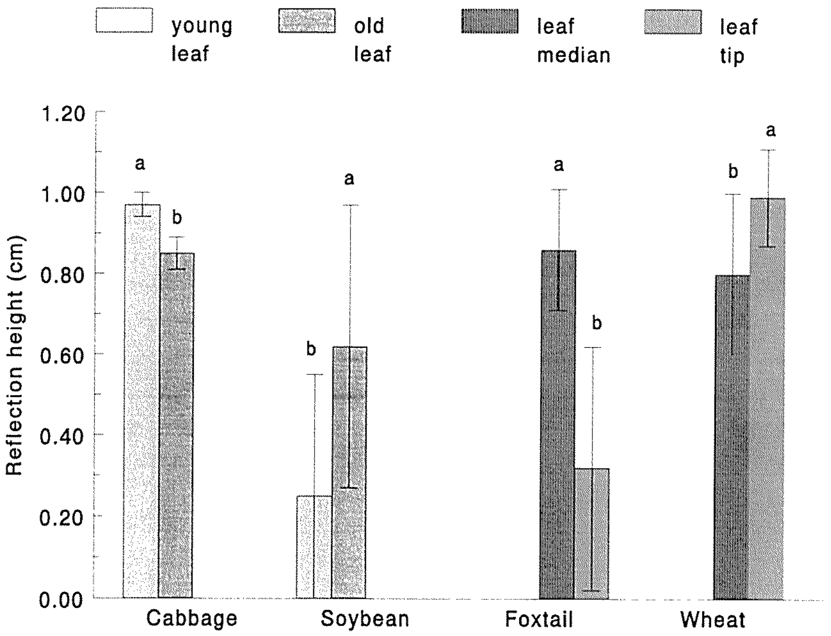

Figure 3. Reflection height of water droplets (230 µm, 0.6 m/s) from different areas of leaves (adaxial surface) of 4 plant species. Vertical bars refer to ± one standard deviation.

Variation with leaves from the same plant species is illustrated in Figure 3. Ten individual water droplets (230 µm, 0.6 m/s) were impacted on either two leaves of different ages from the same plant or, two different areas of the same leaf. When the reflection from young versus old leaves was compared, less reflection was observed from young soybean leaves compared to old ones: just the opposite was true for cabbage leaves. Similarly, the median part of the foxtail leaf showed twice the reflection from that of the leaf tip, while the leaf median gave lower reflection than the leaf tip for wheat leaves. Reflection also varied with the species tested. Cabbage, for example, had little variation among replicates compared to soya where the variability was large. These data illustrate the need for randomization and sufficient replication of plant material.

Reflection of droplets from leaves can be reduced or eliminated if sufficient adjuvants (surfactants) are added to the spray solution. However droplets with very low surface tension tend to roll on the leaf surface and may roll off the edge of the leaf. It is likely that other physical characteristics of the spray solution also effect reflection. Long chain polymers used to reduce drift have been shown to reduce droplet reflection. Good correlation was measured between concentration of the surfactant Kinetic and rebound height (Fig. 4). Rebound was not eliminated at the

concentrations tested but it was reduced significantly at the higher rates. Impaction is a dynamic process in which droplets remain on a leaf for less than 1 ms. The droplet undergoes extensive deformation during which new surface is formed in a short time and unless surfactant molecules are present at the new surface, or can diffuse to it during droplet deformation, surface tension will not be reduced and the surfactant will not reduce rebound. As the surfactant concentration is increased more surfactant molecules will reach the newly created surface during the impaction-process time. When this occurs, surface tension will be lowered and reflection will decrease.

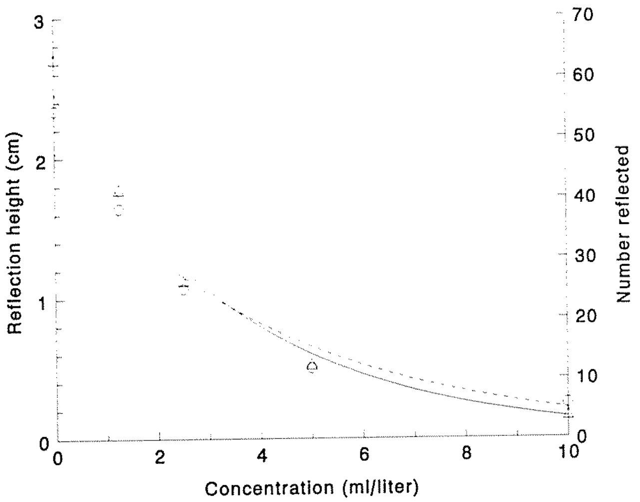

Figure 4. Effect of increasing surfactant (Kinetic) concentration on (O) height ($y = 2.5 - 2.8 \ln x$, $r^2 = 0.992$) and (Δ) number ($y = 47.6 - 2.3 \ln x$, $r^2 = 0.992$) of water droplets reflected from the adaxial surface of wheat leaves.

The oscillating jet system was tested by measuring surface tension of water and ethyl alcohol, two Newtonian fluids. Surface tension of Newtonian fluids should not change when the materials are sheared such as when droplets are formed or impact on leaf surfaces, i.e., equilibrium and dynamic surface tension should be equal. Results for equilibrium and DST for a range of alcohol-water concentrations are shown in Fig. 5.

Results of fitting the DST model to data for two concentrations of 2 surfactants (Igepal CO720 and Surfynol 465) are plotted in Fig. 6 over a range of surface ages from 0.5 to 8 ms. Surfactant composition appears to affect response to surface age. There were great differences among surfactants within one family and among families, as shown by these two examples. Most

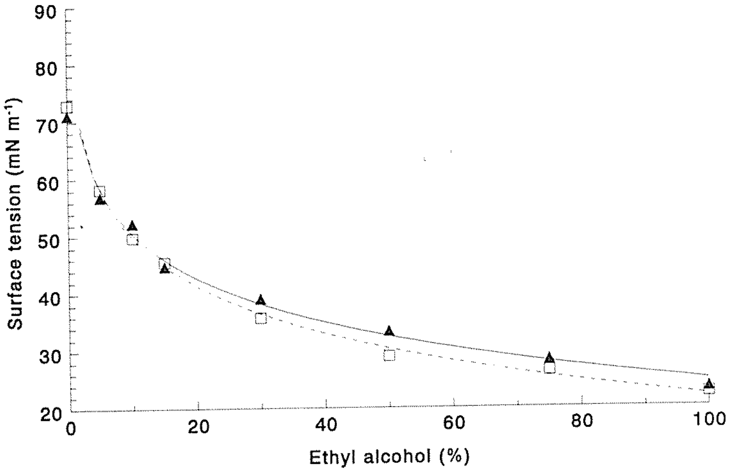

Figure 5. Surface tension of a range of ethanol concentrations obtained by static(□) and dynamic (▲) methods.

surfactants rapidly decreased in DST from values near water at short surface ages (< 2 ms) to equilibrium ST values at long surfaces ages (>70 ms). A few surfactants had low ST even at short surface ages. At 0.25% concentration, Surfynol had a much lower DST than Igepal; at 0.05% concentration, Surfynol DST decreased much more with increasing surface age than DST for Igepal. In general, increasing surfactant concentration improved a surfactant's ability to reduce DST even at short surface ages.

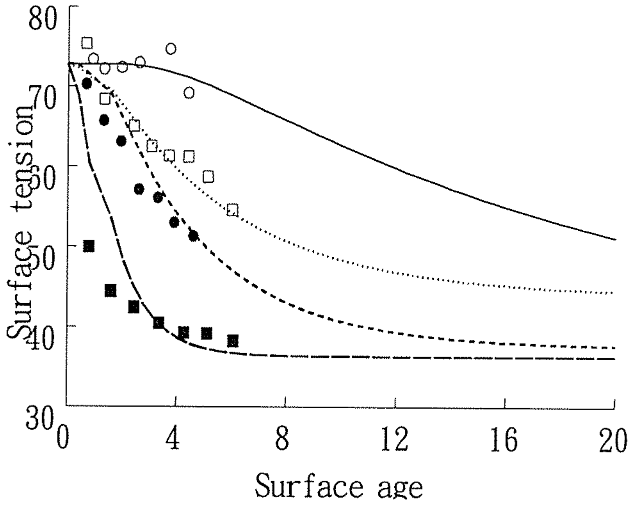

Figure 6. DST of two surfactants, measured (symbols) and computed with Eq. 1 (lines). (O) Igepal, 0.05%, (●) Igepal, 0.25%, (□) Surfynol, 0.05%, (■) Surfynol, 0.25%.

Spray retention

Retention experiments on growing corn, soybean, Johnsongrass, green foxtail, and velvetleaf were made with two adjuvants at two concentrations, with water as the control, sprayed at 100 L/ha. Retention of imazethapyr herbicide used as a tracer at two concentrations is shown as a function of DST at 20 ms in Fig. 7. The data show that the percentage of imazethapyr retained varies with the leaf surface, and that in all cases except for velvetleaf, retention is increased by a decrease in dynamic surface tension.

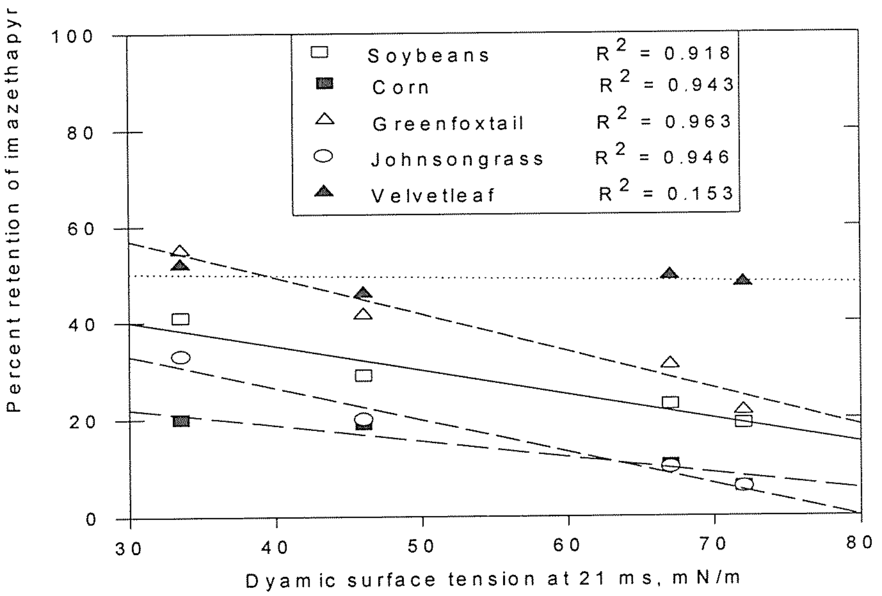

Figure 7. Retention of imazethapyr at a range of dynamic surface tensions.

DISCUSSION

We have accumulated several instruments that are useful in the study of droplet impaction/reflection on leaf surfaces. These studies have provided useful information about how droplets reflect, factors important in droplet reflection and how to reduce droplet reflection. We have also developed a technique to measure dynamic surface tension at short surface ages, DST can be used to predict droplet reflection of a spray mixture much better than static surface tension. We have also shown a positive relationship between DST and the retention of spray on several plant species. As surfactant activity at short surface ages is also important in atomization processes, DST may also be an important physical property in droplet size formation.

ACKNOWLEDGEMENT

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*Names are necessary to report factually on available data; however, the U.S.

Department of Agriculture and Ohio State University neither guarantee nor warrant the standard of the product, and the use of the name of USDA or OSU implies no approval of the product to the exclusion of others that may also be suitable.

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霧粒與葉表交互作用（包括介面活化劑之效用）之研究

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譯稿人：與大農機系謝禮丞副教授

摘要(ABSTRACT)

此篇論文回顧農用霧粒在葉表和人工表面器具開發與測量技術之近期發展情形。大部份的情況，由葉表彈落至地面之霧粒對殺蟲毫無幫助。有兩種均勻霧粒產生器利用高速攝影與錄影之技術來觀察霧粒、葉表之交互作用。由葉表霧粒反彈之研究中的之霧粒在同一作物之反彈隨葉片而異。某些葉片反彈之變化隨葉子之年紀或植物生長之環境（溫室或室外）而不同。有些葉表霧粒反彈現象變化隨葉片位置不同而異，也就是說，霧粒可能大部份由葉尖反彈，與葉中央之反彈比較之下。因此隨機葉片取樣技術和重複取樣就十分重要。震動噴頭方法用來測量動態表面張力（dynamic surface tension, DST）應用在嫩葉期被提出討論且部份使用典型介面活化劑 (surfactant) 之測試結果也發表在此篇論文中。本篇論文中使用之系統為已知測試這些流體特性系統中最好的。作者找到動態表面張力與霧粒反彈有關。所以小心量測噴霧混合劑中的動態表面張力將提供觀察霧粒從葉表反彈產生損失的相似性。依據活化劑分子的薄膜擴散到液氣相交界建立動態表面張力模型。測量的不同葉表年齡範圍之動態表面張力值被用來計算數種介面活化劑的模型常數。

前言(INTRODUCTION)

葉的噴洒應用是一複雜的過程，包括噴洒之霧化、輸送到植物、在葉表的碰撞、留存和組成的成分，植物的吸收等。這些過程都會影響噴洒的效率。葉表的霧粒存留只是噴藥過程之其中一階段，但是它是十分關鍵因為只有存留的霧粒對保護植物有效用而反彈的霧粒可能導致經濟效益之損失及環境污染。

霧粒由葉表留存或反彈是噴藥內容(表面張力和黏度)，噴洒式樣(霧粒大小及速度)及表面形態(軟毛程度、葉脈、微細組織)與目標表面之表層功能群之化學性質之函數。

吾們計劃提供了解噴洒添加物、輸送系統及作物表面再噴洒效力所扮演的角色能由改進霧粒/葉片互動之測量來完成。Reichard 等人(1986)與Reichard(1988)用高速動態攝影與一個分析投影機來觀察與分析由噴霧塊發生的同尺寸的系統與兩個不同霧粒發生器合用以觀察霧粒之碰撞。

霧粒自葉表反彈及霧粒之霧化均佔十分短的反應時間。由吾們尚未發表的實驗室數據中顯示水自液壓噴嘴釋出而形成霧粒的時間小於 3 毫秒(ms)。研究中顯示噴洒的霧粒從葉表反彈通常與葉片接觸的時間少於 1ms。噴液影響這些過程的一個主要的物理特性為表面張力(surface tension)。吾們的研究顯示均衡的表面張力不是噴洒霧粒有潛力從葉表反彈的一項好的指標(Reichard 等人，1997)。

某些介面活化劑之濃度高於 critical micelle 濃度(CMC)即會從葉表反彈，然而高濃度的介面活化劑可完全壓抑反彈。因此，吾們開發一種方法來測量在嫩葉期(young surface age)之動態表面張力(DST) (Reichard 等人，1997)。

這些研究完全著重於觀察與量化霧粒碰撞液面及量測影響此一交互作用之因子。此篇論文將強調這些研究之部分結果或其他衍生自這一系列的研究的論文。

這些研究的目的為開發技術來檢驗及量化霧粒由葉表及人造平面之測量可能影響霧粒交互作用的噴藥輔助物的特性。

用來研究此霧粒/葉片交互影響的許多技術利用均一尺寸霧粒發生器來幫忙檢測碰撞過程的特殊原因。藉由一特別的霧粒發生器附有影像擷取與分析獲得許多型式的有用結果。

試驗器材（EXPERIMENTAL EQUIPMENT）

噴灑應用(Spray application)

指示滴落發生器（Drop-on-demand generator）

此一器具（DOD）可生成單滴、一個尺寸的霧粒，直接為 100 到 800 微米（μm）。靠近噴口所有霧粒之速度均可忽略不計，所以為了得到進給速度之範圍，需調整噴口至目標物之垂直距離。此系統之優點為：有能力將產生之單滴精確地放在目標物表面之各個部位，在一般噴藥應用之尺寸範圍內。此系統同時也可以用來依進給與反彈霧粒之軌跡（用以計算速度）求取反彈高度。此系統之缺點則為無法產生高速霧粒。它只能用來描述霧粒飛行之終端速度或更慢，例如，在離噴灑器具一段距離或經過初霧粒之撞擊之後。

柏格拉得—劉發生器(Berglund-Liu generator)

改良—柏格拉得—劉 (BL) 震動單分解霧質(vibrating mono-disperse aerosol)發生器以得到範圍在 50-1500μm 單一尺寸霧粒之噴霧。再噴孔下方約 1 公分的位置裝一銅環，此點即為首次將液柱打散成霧粒。此環以直流電感應霧粒充電之足以分解液柱為止，在碰撞區提供約覆蓋 1cm^2 之錐狀噴霧。BL 優於 DOD 發生器之一為其產生之霧塊(spray cloud) 與單滴(single droplet)比較之下較為接近模擬液壓噴嘴之使用。由 BL 發生器產生的霧粒速度低於田間使用的速度。

例如，以一個 BL 發生器產生之 250 μm 霧粒一般只有 7.0m/s 之速度，而一般典型液壓噴嘴在壓力為 276kPa 時直接在噴口下量得之速度為 20m/s。另一優點為 BL 發生器有能力依反彈高度決定由一給定表面反彈之進給霧粒之比例。

運動分析系統(Motion analysis system)

<u>高速照相</u>(High-speed photography)

一個 16mm，Hycam，高速照相機被用來攝取霧粒之撞擊情形，此相機為一旋轉稜鏡(rotating-prism)型式，可以拍攝 20 到 11000 張/秒。這個相機配備了一個同步器能調整在要求一定數量底片捲過後才開始一個事件。相機中之氖燈泡(neon lamps)係用來標示 1000 記號/秒在底片之上。此相機設計為通用〝C〞鏡頭。當鏡頭蓋至拍攝距離為 20 公分時，在底片上之影像大小約為 0.7 倍之原件大小。以此安排，拍攝範圍自 11mm 高和 15mm 寬，景深為 3mm。底片為柯達伊士曼 Ektachrome 第 7250 號 ASA 為 400，色溫為 3200K。彩色底片較黑白快且提供較佳的拍攝完成底片之視覺分析。

捲片率(framing rate)選用 6000 張/秒因為可以觀測單獨霧粒之路徑，燈光則使用標準幻燈機之鹵素燈泡。

<u>攝錄運動影像分析系統</u>(Video Motion Analysis System)

此系統(V MAS)用一個黑白攝錄機，配備有一個 newvicon，及一高解析度之影像卡由一表單驅動(menu driven)的動作分析軟體來控制。這個系統提供基本之攝錄功能附較廣之影像檢視、處理與測量功能之選擇。

可疑動支尺規能在螢幕上晝出來，用來量取影像特點，如霧粒之直徑，從表面彈跳之高度及相同霧粒成功影像間之距離。

<u>霧粒照明</u>(Droplet Illumination)

為了幫從 BL 發生器噴出之霧粒照明，兩個頻閃觀測器(stroboscopes)放在 0.05m 後，同時各邊目標葉片與相機長軸約成 45° 角。這頻閃觀測器所使用的閃光頻率比相機的內定頻率(field rate)稍高，因此同一霧粒的數個影像均能在每張底片出現。彈跳軌跡則定義為每一霧粒連續影像之軌跡(見圖 1)。

振動噴射方法(Oscillating jet method)

這個振動噴射(OJ)系統用來測量 DST 之細節由 Reichard 等人(1997)發表。以皮下注射針頭形成橢圓孔發出之藥液為一標準的波形，即為當它從孔口浮現時之物理特質。對頻閃觀測器傾斜 45° 角之一面鏡子用來同時觀測 OJ 波形之前與側視圖。此影像系統在交錯模組(interlaced mode)下提供每張 1976×1234 像素(pixels)之解析度，相對於分別在垂直與水平刻度的 2803 和 2393 像素/公

分。

利用兩個方法在一給定之葉表年齡的表面張力，從波形上做出七個量測值(見圖 2)。在此處的例子，表面張力係由圖 2 中左邊波形之四個量測值決定並用修正的波爾公式(Bohr equation)計算求得(Thomas 和 Potter,1975)。

解在增加葉表年齡的表面張力是決定於波形尺寸從孔口增加距離直到因毛細管不安定性使噴液破裂，或是直到振動減少到振幅小到無法測試為止。為了計算測量表面張力處之表面年齡，從孔口到 $Rmin_m$(用來計算表面張力之兩個成功最大值間之最小值)之垂直距離被噴嘴軸向速度除而得。

DST 模型(DST model)

DST 模型是由 Brazee 等人(1994)利用薄膜擴散(thin-film diffusion)理論發展出來。此模型，DST，σ(t)，在表面年齡 t 是

$$\sigma(t) = \sigma_m + m_0 C_0 \left[1 - \frac{2}{\pi} \sum_{n=0}^{\infty} \frac{(-1)^n e^{-\pi^2 D (n+\frac{1}{2})^2 \frac{1}{a^2}}}{n + \frac{1}{2}} \right]$$

其中 m_o 為一常數相依於溶液平衡 ST，介面活化劑之濃度 C_o，與水的表面張力 σ_m；D 是介面活化劑之擴散度；a 則是明顯的界面薄膜厚度。模型的開發目前與 DST 研究一起利用最大氣泡壓力和振動噴射方法。

結果與討論(RESULTS AND DISCUSSION)

霧粒碰撞與反彈(Droplet impact and reflection)

霧粒碰撞與反彈是否從葉表反彈最重要的因子即為葉面本身。葉子有良好的蠟層者，如甘藍葉，通常可提供霧粒彈跳之理想表面。作者們曾嘗試製作人造表面來進行霧粒反彈試驗，但都沒成功。21 種植物用來做水滴反彈試驗。約 1/3 無反彈，1/3 有一些反彈及 1/3 幾乎反有碰撞到葉面之水滴均反彈。一些主要農作物，如小麥和稻穀，有高度反彈之現象。

在同一種植物品種，其他次要因素也能影響霧粒之反彈，作者們發現較小的作物(4 個葉齡階段)在溫室中的理想狀態生長，於冬季間無法產生典型的蠟層，因此將無法反彈霧粒；同樣類似的作物生長在戶外或長到較大的時期即有反彈霧粒的現象。

圖 3 顯示相同種的作物在不同葉齡之反彈高度，10 顆單獨水滴(230□m，0.6m/s)碰撞同一作物之二片不同葉齡之葉片或同一葉片之二個不同部位。當比較新、老葉之反彈時，大豆葉之新葉反彈較老葉少，而甘藍葉則呈相反結果。

類似此一狀態，狐尾草之葉中反彈為葉尖之二倍，而小麥葉之葉尖反彈量卻較葉中為多。反彈亦隨試驗品種變化而異。例如甘藍葉之試品間之變異小，相形下大豆之變異則大。這些數據顯示作物取樣之隨機性與足夠的重覆樣本是必需的。

反彈效果可由添加足夠的介面活化劑至藥液中來降低或消除。然而表面張力小的霧粒會在葉面上滾動甚至由葉緣滾落。似乎藥液之其他物理特性也會影響反彈。長鏈聚合物用來減少飄移也同時減少霧粒之反彈。介面活化劑 Kinetic 之濃度和彈跳高度有良好的關係(見圖 4)。在濃度測試中彈跳高度並沒有完全消除但是高濃度可明顯地降低彈跳高度。當霧粒停留在葉片少於 1ms 時，碰撞為一動態過程。霧粒在極短時間內新表面形成時忍受廣泛之變形，於此時除非有介面活化劑分子呈現否則在霧粒形成時可能會擴散，表面張力將不會減少，同時介面活化劑將無法減少彈性。當介面活化劑之濃度增加，更多的介面活化劑分子在碰撞過程中到達新形成的表面。於是，表面張力降低，反彈就減低了。

振動噴射系統之測試是靠量測水和酒精(ethyl alcohol)，二種牛頓(Newtonian)液體之表面張力而成。牛頓液之表面張力在物質互享時應不會改變，如在霧粒於葉面上形成或碰撞時，也就是說平衡和動能表面張力應相等。酒精一水濃度範圍之平衡和動態表面張力之結果整理於圖 5 中。

將 DST 模式應用到 2 個介面活化劑(Igepal CO 720 和 Surfynol 465)之二種濃度之數據，可得的結果繪於圖 6 中，其中葉齡範圍為 0.5 到 8 ms。介面活化劑組成成分明顯地影響表面期(surface age)。介面活化劑在一家族及家族間之差異十分大，以下兩例說明之。大部分的介面活化劑由之 DST 值迅速降低短表面期(< 2 ms)接近水的值到長表面期(>70 ms)之平衡 ST 值。極少的介面活化劑甚至在短表面期有低的 ST 值。在濃度為 0.25%，Surfynol 之 DST 值較 Igepal 低許多；在濃度 0.05%時，Surfynol 的 DST 較 Igepal 的 DST 隨漸增的表面期降得更多。一般而言，增加介面活化劑濃度增進介面活化劑降低 DST 之能力，即使是在短表面期。

<u>噴灑存留</u>(Spray retention)

存留試驗作物對象存生長中的玉米、大豆、Johnson grass，綠狐尾草、和天鵝絨草，二種濃度的二個補助物，以水作控制，噴酒 100 L/ha。Imazehtapyr 除草劑之保存用來做軌道追蹤，利用二種濃度作為圖 7 中 DST 在 20 ms 之函數。數據代表 imazethapyr 之百分比之存留度隨葉表不同而不同，在除了天鵝絨草以外的情況下均成立；存留隨動態表面張力之減少而增加。

討論(Discussion)

吾們累積了數個有用的器具應用在霧粒碰撞/反彈在葉表之研究上。這些

研究提供有關霧粒如何反彈、霧粒反彈的重要因子及何減低霧粒之反彈的資訊。吾們同時也開發了新技術測量在短表面期之動態表面張力，此 DST 用在預測噴液之霧粒之彈跳較靜態表面張力為佳。吾們也以數種作物品種提供 DST 和噴液存留的正向關係。因為介面活化劑的活性在短表面期之霧化過程很重要，所以 DST 可能是形成霧粒大小之重要物理特性。

Methods and Techniques in Determining Spray Quality

R.D. Fox, R.C. Derksen, H.E. Ozkan, R.D. Brazee[1]

Abstract:

The efficacy of chemicals sprayed on plants to control pests depends on chemical formulation, concentration and deposit pattern on foliage. The application pattern on the leaf is the key to optimizing efficient utilization of pesticides. The current goal of an ideal application is to apply spray uniformly throughout the plant canopy. However some pests are concentrated in specific sections of the canopy, i.e., the bottom center, the top center, or perhaps on the under side of leaves. In these cases we may want to target spray to the infested regions and a non-uniform pattern would be preferred. At a smaller scale, the deposit pattern on individual leaves or fruit may be important. Several techniques for assessing the deposit pattern are discussed. Again, the specific target pest or pesticide used may determine the best deposition pattern.

INTRODUCTION

The adoption of precision farming on a wide scale would reduce pesticide use by permitting IPM principles to be applied to pesticide spraying on a more precise scale, equivalent to the block size used in each field. Precision farming will require sprayers that can control application rate and other spray variables while spray is being applied. Spray efficiency could be improved still more if optimum coverage and drop size relationships were known and integrated into spray controller algorithms during field operations.

The efficacy of chemicals sprayed on plants to control insects and diseases depends on the chemical formulation, its concentration and its deposit pattern on targeted area (leaves, fruits, branches, etc.). With increasing pesticide costs and the development of highly active chemicals, it is essential to apply pesticides effectively. Active ingredients should be applied in the most effective droplet sizes and uniformly on the foliage with optimum distance between the droplets (Kirk et al. 1992; Alm et al. 1987; Furness, 1993; Furness et al. 1993). Sprayed areas with large between-droplet distances may not effectively control insects or diseases (Magarey et al. 1993). Chemical exposure without killing all of the insects may result in survival of pests resistant to the chemical (Alm et al. 1987).

To overcome inefficient coverage an overdose of chemical is often sprayed (Reichard et al. 1987). Using excess chemical is expensive, may pollute the environment and leave hazardous residues on edible fruits and vegetables. Better coverage of cotton plants has resulted in lower chemical use and the ability to use less toxic chemicals while controlling insect and disease (Manor et al. 1991; Zur et al. 1991;

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Veierov et al. 1994). Kalter (1992) found that detergent applied with vertical air ducts that gave uniform adaxial and abaxial leaf coverage throughout the canopy was nearly as effective as pesticide in controlling Bemisia Tabaci on cotton. Clearly, deposit pattern was important in control using detergent.

I. Factors effecting optimum spray deposit pattern

Spray application effectiveness could be improved greatly if the desired spray pattern on the target leaves was defined precisely. Unfortunately, many factcrs affect the optimum spray deposit pattern, so the best spray deposit for one situation may not be optimum for another crop or pest. Currently the goal of all spraying operations is to produce the same deposit amount and pattern on all parts of the plant canopy. This is never achieved. Sometimes we adjust the droplet size to provide better control of specific pests, but canopy penetration, bottom of leaf coverage, targeting pests in specific parts of the canopy are not routinely addressed with current technology and spraying practices. What size droplets are optimum for each crop/pest? Several studies have found that smaller droplets are more effective when using certain pesticides for control of specific pests such as: spruce budworm, Himel (1969), spider mites, Alm et al. (1987), whitefly, Mboob (1975), and eggs, Munthali and Wyatt (1986). Other pertinent questions follow. How much can proper timing reduce the dose required for pest control? Can we pinpoint the optimum time for spray applications? Is a uniform deposit pattern the best for all pests? Ford and Salt (1987) provide a complete review of spray deposits and their transfer to insects.

Over time, I believe many of these questions will be answered, and new and more effective pest control procedures will be developed. Among these might be controlling migrating pests at the beginning point of the migration; intercepting migrating pests en route; controlling pests at the most susceptible stage of their growth cycle; making better use of pest activities to help spread pesticide to optimum target sites; etc.

Target pest characteristics that define the most effective spray application/optimum deposit pattern include: site of canopy activity; feeding habits; movement patterns; life cycle; alternate hosts; egg deposit sites and patterns; and characteristics of all growth stages. Adams et al. (1987) measured the relative influence of drop size, droplet density, pesticide concentration, formulation and time of application on control of glasshouse whitefly. Sharkey et al. (1987) present a model that defines an optimum spray deposit for sedentary pests. Hall et al. (1995) developed a model for predicting the transfer of sprayed droplets to feeding larvae. Falchieri et al. (1995) measured the effect of spray droplet density and pesticide concentration on the feeding habits and mortality of gypsy moth larvae.

The site and type of activity of the pesticide is also an important factor on defining deposit patterns and spray targeting. Some pest control agents are effective because they repel the pest. I believe that bio-control agents will include more products that use this type of action. Similarly, some spray materials are irritants, which cause the pest to change their behavior. Toxic chemicals may have several modes of action. The insect may be affected by external contact with the sprayed material or may have to ingest the spray before it becomes active. Systemic chemicals in general have less critical deposit pattern requirements than non-systemic agents. However, some systemic materials are more effective if they are applied in higher or lower concentrations, dry

slower, or are applied in larger droplets.

Measurement methods

Introduction

Spray deposits from most applications produce great variability among collectors, even the same collector with different replications. It is difficult to obtain statistically significant differences among treatments, even if a large number of replications are made. Therefore many analysis methods developed recently have the goal of improving the speed of measurement, so that greater number of samples can be collected.

Collectors

The best collector for spray deposits is probably actual leaves. However, using leaves contributes to the difficulty of image analysis. First or all leaves are not flat; they have veins, ridges and undulations. It is difficult to obtain a uniform camera focus when the image is captured. Any out of focus sections of the image makes measuring droplet size (and even identifying small spots) questionable. Leaves also are difficult to store, so must be processed quickly. Leaves are different sizes, so an additional target size measurement is required. If leaves are picked directly from the target plant, then multiple passes with collectors in the same location can not be made. For these reasons, artificial (non-plant) materials are often used as spray droplet collectors. Sample leaves should always be tested for background deposits of the tracer material. One of our experiments was ruined because previously sprayed fungicide (copper) was found in large amounts on all leaves.

Other materials used for collectors include plastic sheets, filter and other papers, metal plates, strings, cloth, glass slides, and screen. Collectors that are not plant leaves or other living plant parts are often called 'artificial' collectors or targets. Properties of the collector should be considered before they are selected. Some targets like glass slides and plastic tape may have problem with spray run-off, if they are located close to the sprayer and high volume rates are applied. The tracer material should be tested with the collector to determine how much of the dried tracer can be washed from the collector. Some materials (cotton strings) tend to adsorb some fluorescent tracers and only 50% of applied spray may wash off. Some filter material (especially fiber-glass) tends to fall apart during washing, especially if alcohol is used as a solvent. The fibers tend to attenuate the light beam in some instruments (fluorometer) which results in erratic readings.

Tracer materials

Tracers include pesticides, fluorescent materials, salts, metal compounds, and food coloring or other dyes. An actual formulated pesticide is probably the best tracer, however, workers may be exposed to the pesticide for an extended time during experiments. Analysis for pesticides usually requires a Gas Chromatography (GC) or other expensive methods. For these reasons, other tracer materials are used to simulate the pesticide.

Salt sprays, such as foliar fertilizer, have been used as tracers. They can be detected with inexpensive conductivity meters and are readily soluble in water. In general, the detection threshold is not as low as for some other tracers and there are many sources of contamination. Metal compounds (copper, manganese, iron, etc.) have been successfully used. Copper salts can be measured with an inexpensive instrument such as a colorimeter, however, sensitivity thresholds is not a low as some other tracers.

Other metals require instruments such as atomic absorption spectrometers (AAS) for detection, but are usually quite contamination free.

Fluorescent tracers are widely used, but they have several problems that must be considered before they are used. An ideal fluorescent tracer would be soluble in water, fluoresce when dry, and not degrade in sunlight. We have not been able to locate many tracers that meet these criteria. Many florescent materials degrade (their fluorescent intensity decreases) when they are exposed to ultra-violet (u-v) radiation. Experiments conducted in sunlight may result in degraded samples. We have found that degradation is greater when spray droplets are liquid. Therefore the degradation rate is likely to depend on droplet size. Many fluorescent materials are powders (about .1 to 1 µm) and some questions have be raised about how well they may be distributed in small spray droplets (1 to 10 µm in diameter). There are many fluorescent materials available, in many colors. Therefore compatible tracers can be found that can be mixed without affecting the measurement of either. Often we like to use two sprayer treatments in the same weather conditions, and being able to separate tracers applied to the same collectors is very convenient.

Other factors

The formulation of the spray mixture must be considered. Most active chemicals contain adjuvants such as solvents, surfactants and other materials to stabilize the product and for easy mixing in water. Either blank pesticide (the same formulation without the active ingredient) or some common surfactant should be added to the tracer to simulate actual pesticide formulations. We have found that even mixtures of dry fluorescent tracers in water may produce sprays with different $D_{V0.5}$. Adding surfactants to the spray mixture will also change the amount of droplet spreading on leaf surfaces (or any other collector surface). This is a factor in image analysis of dried spray droplets.

Another consideration for spray trials is the quality of the source water used for the tank mixture. In the U.S.A. the quality of the water may change from one section of the country to another. Some water contains many mineral ions that may affect the solubility of tracers. In some cases, a celating agent is added to improve solubility. The pH of the water may also affect the mixing of tracers or other chemicals.

The sensitivity (useful threshold of detection) of instruments is important in determining whether a tracer system can be used for a particular experiment. When measuring deposits near a sprayer, such as deposits on a canopy or the ground, measuring small tracer amounts is not as important as when measuring deposits several hundred meters downwind in a drift experiment or on very small collectors (simulating a bud). A list of the instruments mentioned above, in order from least sensitive to most sensitive are: conductivity meter, colorimeter, AAS, GC, and fluorometer. GCs and fluorometers can detect deposits as low as a few parts per billion.

Wash and analyze

A standard method of measuring deposit is to wash spray collectors and analyze the wash solution for a tracer. The result of these measurements is spray deposit per unit area, which can easily be converted to percentage of applied spray. A disadvantage of this method is that many different deposit patterns may produce the same dosage, e.g., one large droplet could give the same result as 1000s of small droplets. This is still a good technique to use in addition to deposit pattern measurements, to evaluate the total deposit and to account for the total amount of spray applied.

Porskamp et al. (1993) collected spray from orchard sprayers on samples of filter paper mounted on a vertical tower. The filter paper samples were gathered quickly and weighed to determine the amount of spray deposits.

Fox et al. (1998) reported on a spray deposit analyzer developed by D. Reichard. In this system, a plastic tape (usually in a metal holder) is exposed to spray containing a small amount of a salt. The tape is pulled through the analyzer, washed with distilled water, and conductivity of the wash water measured.

Salyani and Serdynski (1990) developed an electronic sensor to measure impacting droplets. The instrument consisted of an array of parallel conductors with a voltage potential that increased as the number, size, and conductivity of spray droplets impacting on the sensor increased.

Manual visual measurement

Another traditional way of measuring deposit is by manual observation. Manual techniques may range from rating spray coverage patterns against a set of standard patterns to counting number of droplets in a sample area and measuring droplet size with a microscope. Making measurements with a microscope is tedious, time-consuming work, so the number of samples is usually limited. But the results can be quite accurate, because the human observer can evaluate spray pattern problems such as droplet overlap, variable background intensity, irregularly shaped spots, and differences in spot density that may be a problem for video-based imaging systems.

Scientists at LPCAT used a boom spray with colored dye to spray a uniform snow field. Areas receiving different application rates were clearly visible and photographs clearly showed the deposit pattern. However, collecting samples and analyzing for the dye was not successful.

Computer aided measurement

A wide range of computer based image analysis systems are now available. Most of these systems have associated software programs that implement easy computation of spot characteristics. Spot characteristics include droplets/cm^2, area coverage, and drop size distribution. These software routines may include calculation of equivalent spherical diameter, width and breadth of the spots, estimated spot overlap, and on and on. Many editing and image enhancing routines are built into the software. The software also includes macro capability wherein a series of analysis steps can be combined into one command. Thus, image analysis of a large number of targets can be carried out quickly and consistently.

Panneton and Drummond (1991) developed an imaging system with automatic focus, correction for background variation, and identification of overlapping spots. They showed that lamp intensity, as controlled by supply voltage was critical to accurate spot size measurement. Derksen and Jiang (1995) developed an automated vision system to characterize deposit. This system used computer controlled positioning with automatic focusing and image enhancement and feature extraction. They measured percent area covered, spot size, and spot roundness while using fluorescent tracers.

Franz (1993) used a hand-held scanner to quickly scan water sensitive paper and kromecoat targets for spray coverage. He developed a computer program to calculate droplet characteristics. Sample deposit measured with this system was consistent for a limited range of droplet sizes. In later studies, results from this system agreed with deposits measured with washed micro-tubing.

LPCAT has sprayed a black dye, nigrosine, in water on clear plastic tape. The tape is illuminated from below and the spray pattern image captured. Many images can be captured along the length of the tape. With a good image analysis program and a macro, a large sample of spots can be obtained quickly.

A epi-fluorescent microscope can be used to investigate spray deposit patterns. This instrument used low power lens, a strong UV light source, and interchangeable filter sets to capture images of fluorescent tracer in dried spray droplets. Standard image software is used to measure the droplet size and coverage of the captured frames. The image captured in each frame is about 5 to 10 mm in each dimension, therefore, many images must be measured to obtain a large droplet sample size. However improved resolution allows for the capture of smaller droplets than systems without microscopes. In addition, when leaf surfaces are used, it is easier to maintain a uniform focus over a smaller image area. Krause et al. (1993) used an Scanning Electron Microscope combined with X-ray dispersion to measure spray coverage using metal tracers. Coverage of 0.5 by 0.6 mm areas could be measured and the system could also confirm that the deposit contained trace element. Total area measured is necessarily limited by the size of each sample.

Problems with image analysis

Image analysis has several inherent problems that must be resolved before spray droplet pattern analysis can proceed. The video camera/imaging board system will always produce a band of gray between the spots and the background. Therefore, the size of the spots will change depending on the gray-level selected as the dividing line between white and black when the image is transformed to binary form. Some software systems use the gradient of gray scale with distance from the spot to automatically select the edge of the spot. Edge enhancing routines of many types are also available. Another problem is that the collector background may not be uniform throughout the entire image area. This is often true if leaves are used to collect droplets. Poor lighting may also cause background variability. Some software is capable of measuring the difference between spot density (gray-level) and background density at all points in the image and to correct the image so that the spot/background differences is equal throughout the image. Large spray application rates may produce too many spots. If the coverage is too great, many droplets will overlap, and it will not be possible to measure spot size accurately. The percent coverage can still be measured even if spots overlap. Some software routines are available for correcting for spot overlap, but they must be used with care. Another choice that must be

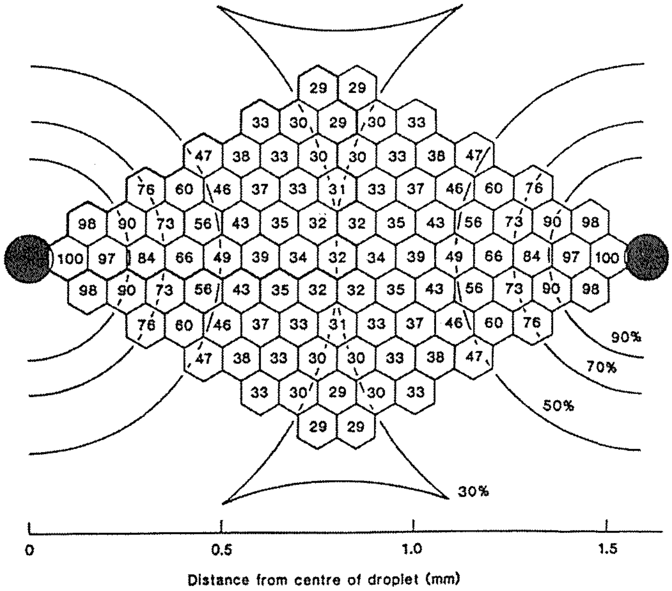

Figure 1. Estimated percent mortality of whitefly larvae between 118 μm droplets spaced 1.6 cm. From Adams et al. (1987)

made when selecting an imaging procedure is the smallest droplet size to be measured. In most cases, as the spots become smaller, they will gradually disappear, i.e., the amount of tracer material in the droplet is so small that the spots can not be distinguished from the background. Smaller spots can be measured if a greater resolution is chosen. Image area per frame is reduced to increase resolution. Then the number of images analyzed must be increased to measure the same number of spots (at least the same percent area coverage, because the smallest spots will not contribute much to the area coverage). Displaying small spots on a binary image usually requires that the gray-level cut-off be set closer to background. This may display some background points as spots, which will cause errors in the spot count. Measuring small spots (spots less than 3 pixels in each dimension) will always have a risk of including spots that are not real spray droplets.

It is important to remember the first rule of image analysis is always capture good quality images. No matter how clever the image enhancement routine, it can never produce good data from poor quality images. Time spent on improving the quality of captured images is much more productive than time spent trying to repair poor quality images.

Other measures of spray patterns

Other methods of quantifying spray deposit patterns have been proposed. Adams et al.(1987) applied uniform-sized droplets in a triangular pattern to measure the effect of drop size, pesticide concentration, and distance from the drop on the mortality of 1st instar whiteflies. From their measurements, they constructed a theoretical table of the effect of distance from uniformly spaced droplets on larvae mortality (Fig. 1). Because of the time required to conduct such studies and to construct such tables, this research approach has not been continued or expanded.

Washington (1997) measured coverage pattern differences for droplets of different size used for controlling fungi on banana leaves. He described 'the zone of inhibition' surrounding a fungicide droplet deposit on the leaf surface. Others have attempted to define this zone of activity around spray deposits.

Manor et al. (1994) defined an Effective Radial Distance (ERD), which is defined as the region surrounding a droplet or spray deposit on which the active ingredient has the desired affect (control) on the target insect. ERD defines a region about each deposit that can be easily calculated with imaging software and which is not greatly affected by deposit shape or size, only by the space between deposits (Fig. 2). An accurate measure of spray deposit on test media could account for variability between treatment efficacy. They computed ERD from spots on an

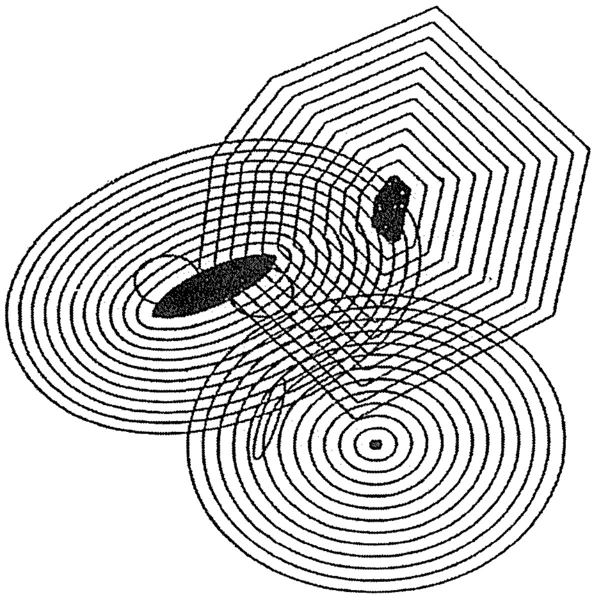

Figure 2. ERD from different shaped droplets.

image by adding one row of pixels around all of the spots in the image. This added one pixel to the value of ERD. After each row of pixels was added, the percent area coverage was calculated. In this was, a plot of ERD vs percent area coverage was developed. A commercial imaging system that does this calculation is available from BarGold Electronics Ltd. By comparing ERD plots for several spray deposit patterns with efficacy studies for different pests and pesticide combinations, criteria for the optimum ERD could be developed. Again this system would require a large experimental program to develop optimum criteria for a range of pests, pesticides, drop sizes, concentrations, etc.

Adams et al. (1988) used a video system to track the movement of aphids that were exposed to a range of pesticide droplet sizes and concentrations. They measured distance walked, number of contacts with spray droplets, and time spent in the region treated with spray droplets. They found that contacts with droplets increased with distance walked, however, no factor correlated with subsequent larvae mortality. Other video systems track the movement of several insects/larvae placed in an enclosure that contains samples of pesticides or attractants. This system measures the effect of the chemical on the movement of target pests.

Spray deposit patterns are likely to be more important when bio-control agents are used. These agents will likely be less toxic and slower acting than chemical pesticides, therefore placement and distribution of bio-control agents will be even more critical than chemical agents.

DISCUSSION AND SUMMARY

Spray deposit patterns are important in the control of crop pests. This is especially true if we attempt to reduce the amount of applied pesticide to a minimum. Effective use of small amounts of pesticide will require accurate placement within the canopy with the habitat of specific pest targeted for maximum spray delivery. Then spray deposit patterns on specific canopy sections containing the pest will be critical to further reduction in the amount of pesticide required for control. Use of biological control materials will probably require even more accuracy in the deposit of the pest control agent.

The application of imaging analysis to spray deposit analysis promises to enhance the capability of scientist to measure and define spray patterns. This is the first step in identifying spray patterns that are the most effective. It is likely that the optimum spray pattern will be different for different pests, pesticides and crops. However, we can hope that similar spray patterns will be best for a range of pests with similar feeding and habitat characteristics, and for pesticide with similar modes of action. We will also have to design sprayers that can be easily configured to spray different crops and pests. Crops with different canopy shapes, limb strength and resilience, etc. will require modifications in air jets, and spray release points for maximum spray deposit efficiency.

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農藥施噴品質判定之方法與技術

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摘要

農藥施噴用於控制作物蟲害的功效與農藥配方、濃度和沉積附著(deposit)在葉面的型態有關，在葉面上的施噴型態是在使用農藥上，能達到最佳效率的關鍵。目前應用的理想目標是能均勻的施噴在作物的株叢內，然而有些蟲害是集中在株叢的特定區域，譬如底部中央、上部中央或葉片底面，對於這些狀況，農藥施噴在蟲害群居區域和不均勻的型態是較佳的施噴方式。在較小規模施噴下，沉積附著在個別葉片或果實上的型態可能很重要，此論文將討論沉積附著型態評估的一些技術，而最好的沉積附著型態決定於蟲害的種類和使用的農藥。

一、前言

在大規模作業下，採用精耕以蟲害防治整合原則，應用於農藥施噴更加精確上而能降低農藥的使用，精耕是在需要農藥施噴時，施藥者能控制施藥量和其他施噴的變數。當霧滴大小與最佳附著覆蓋(coverage)已知，進而將其整合在田間操作的農藥施噴控制邏輯中，農藥施噴的效率可以進一步改善。農藥施噴用於控制作物蟲害和病害的功效與農藥配方、濃度和附著在目標物的型態有關，有效的成分應該用在最有效的霧滴尺寸和以最佳霧滴間距均勻分布在葉面上，施噴區內大的霧滴間距可能無法有效的控制病蟲害，當農藥無法殺死所有蟲害時，可能導致存活的蟲害具有抗藥性。

為克服沒有效率的附著覆蓋，經常會施噴過量的農藥，使用過多農藥除了花費增加外，亦會污染環境並且有害的殘留物也會遺留在可食用的蔬果上，譬如棉花樹有較佳的附著覆蓋，能減少農藥的使用和使用毒性較低的藥物就能控制病蟲害。

二、最佳農藥施噴附著型態的影響因素

假如目標葉面的施噴型態能精確的定義清楚，則可以很顯著的改善施噴效

用。但是影響施噴的最佳沉積附著型態有很多因子，因此對於特定狀況的最佳沉積附著可能並不適合另一種作物或蟲害。現階段所有農藥施噴作業的目標是對於作物的整個株叢產生相同的附著量和型態，但此目標從未達成。有時調整霧滴尺寸能夠較有效控制特定蟲害，但是以目前的技術和施噴習性，並沒有注意葉面底部附著覆蓋和株叢特定部分的蟲害。至於對於每一種作物或蟲害的最佳霧滴尺寸是多少呢？許多研究已經得到較小的霧滴其效用較大。另一些問題如適當的施噴時間能減低多少蟲害控制所需的用藥量？我們是否能精確指出噴藥的最佳施噴時間？均勻的沉積附著型態對於所有蟲害都是最好嗎？

控制移居蟲害在遷移的初期、在中途攔截遷移蟲害或在蟲害生長循環中最易受影響階段控制蟲害，和利用蟲害的活動幫助農藥散佈到最佳目標點等方法可能是最有效的方式。在最有效的施噴型態上，對於目標蟲害特徵的定義包含：在株叢的活動點、取食習性、移動型態、生命循環、產卵點和型態與所有生長階段的特徵。

農藥的作用點和型態，對於制定沉積附著型態和施噴目標物，是一個重要因素，一些蟲害控制介質很有效是因為可以驅逐蟲害，同樣的，一些施噴物質有刺激性而造成蟲害改變其習性，有毒農藥可能有很多反應方式，蟲害可能因為與施噴物質接觸或在其發生反應前攝取而受影響。

三、量測方法

前言

對於大部分應用上，收集器內的施噴附著有很大變異，縱使相同的收集器在重複試驗時亦同。即使執行大量的試驗，在各種處理上也很難得到統計上的顯著差異，因此最近很多分析方法已經被發展出可以改善量測速度，所以較多的樣本數量可以被收集。

收集器

最好的施噴收集器可能是實際的葉片，然而使用葉片會有影像分析的困難，因為葉片不平整而且有葉脈、葉脊和波狀，當影像被擷取時，很難得到均勻的對焦，任何焦距不準部分的影像將使得量測的霧滴尺寸有問題，另外葉片不方便儲存所以必須迅速處理，葉片具有不同的尺寸所以需要額外的目標面積量測，因為這些理由所以人工材料經常被用來做為農藥施噴的霧滴收集器。

做為收集器的其他材料包含：塑膠片、濾紙、金屬片、布線、和玻璃片等，不是作物葉片或其他部位的收集器通稱為人工收集器，但收集器在使用前應考

慮其特性。玻璃片和塑膠帶如太接近於噴霧器或高施噴量時，可能會有施噴流失的問題，此外需要以收集器測試有多少乾追蹤劑會被清洗掉，有些材料如棉線會吸收螢光追蹤劑而只有施噴量的 50%會被清洗掉，一些纖維材料在清洗時會流失，尤其是以酒精為溶劑時。

追蹤劑

追蹤劑包含農藥、螢光材料、鹽基、金屬混合物、食用色素和其他染料等，實際的農藥成分可能是最好的追蹤劑，但是可能造成執行試驗人員暴露於農藥中過量。農藥成分分析經常需要氣相層析儀或其他昂貴方法，基於這些理由其他追蹤劑被用來模擬農藥的施噴型態。

像葉肥的鹽基施噴已被用做追蹤劑，其可使用不貴的導度計檢測並且可溶於水，一般其檢測遲滯並不像其他追蹤劑般的低而且有許多污染源。金屬混合物已被成功的應用，銅鹽能用像色差計之類的儀器量測，但是其遲滯靈敏度不似其他追蹤劑低。而其他金屬需要像原子吸收光譜儀的儀器來檢測，但通常不會受到污染。

螢光劑已被廣泛的應用，但在使用前必須先考慮一些問題，一個理想的螢光追蹤劑應要可溶於水，乾固時能發螢光而且在陽光下不會衰減，但還沒有任何追蹤劑符合這些條件，許多螢光材料當暴露在紫外線下都會衰減，所以在陽光下執行試驗會導致樣本的衰減，而且衰減率和霧滴大小有關，螢光材料是粒徑 0.1-1mm 的粉體，其在霧滴中的分布情形是一個問題，目前有各種不同顏色的螢光材料可供使用，因此相容的追蹤劑可混合一起而不影響量測值。

其他因子

霧滴的混合成分必須被考量，大部分有效的化學物包含像溶劑和介面活化劑(surfactant)的輔助劑，用於穩定生成物和使其易於混合於水中。無效用的農藥或一般介面活化劑應加入追蹤劑以模擬實際農藥成分，乾燥的螢光追蹤劑混入水中被發現會使農藥施噴有不同的 50%體積下的霧滴直徑(Dv0.5)，加入介面活化劑於噴藥中也會改變霧滴散布在葉面的量，這些在對乾燥霧滴的影像分析時這是一個因素。施噴試驗的另一個考量因素就是用於混合器中水源的品質，水中含有的礦物質可能影響追蹤劑的溶解度，水的 pH 值也可能影響追蹤劑或其他化學物質的混合效果。

儀器的靈敏度在決定一個追蹤系統是否適用於一特定試驗將很重要，當量測的沉積附著非常接近於噴霧器時，量測少量的追蹤劑將不像飄移試驗時量測幾百公尺遠的追蹤劑或很小收集器上的追蹤劑般重要。上述所列儀器由最不靈

敏到最靈敏的順序依序為：導度計、色度計、AAS、氣相層析儀、螢光度計，其中氣相層析儀和螢光度計能量測到附著量在數十億分之一的精度。

清洗和分析

量測沉積附著量的標準方法為清洗霧滴收集器，並對清洗溶液中的追蹤劑做分析，量測的結果為每單位面積上的霧滴附著量，其值可輕易的轉換成施噴應用的百分比。此方法的缺點是不同的沉積附著型態會有相同的附著量，譬如一個大霧滴和上千個小霧滴有相同的結果，除了附著型態的量測之外，評估全部附著量和施噴的全部使用量，這還是一個很好的技術。

人工量測

另一個傳統量測附著量的方法是以人工觀測，人工技術可對照一組標準型態而將施噴型態分類，並在一個樣本面積上計算霧滴數目和用顯微鏡量測霧滴尺寸。以顯微鏡量測是繁雜且費時的，因此量測樣本通常有所限制，但是其結果非常精確，因為人工觀測能分辨施噴型態的一些問題，譬如霧滴重疊、背景強度、不規則形狀，這些問題對機器視覺系統可能都是問題。

電腦輔助量測

目前有很多的電腦視覺分析系統可供使用，大部分都附有軟體用於計算量測點的特性，量測點包含單位面積的霧滴數、附著覆蓋面積和霧滴大小分布。軟體可計算霧滴等效圓球直徑、點的長寬和估算重疊等等，很多編輯和影像加強程式都建立在軟體中，軟體並有巨集的功能可將一串分析步驟結合成一個指令，因此大量目標物的影像分析可以非常快速的處理。

一 epi 螢光顯微鏡(epi-fluorescent microscope)能用於探討施噴沉積附著型態，此儀器使用低功率鏡片、強紫外光源和可交換濾片，以捕捉乾霧滴中螢光劑的影像，標準影像處理軟體適用於量測畫面中霧滴尺寸和覆蓋率，捕捉影像的畫面每邊長約 5-10mm，因此需要量測很多影像才能夠得到大量的霧滴樣本。然而改進解析度能捕捉比沒有顯微鏡系統更小的霧滴，此外當應用在葉片時，將較容易在一小影像面積內保持均勻的對焦。

影像分析的問題

影像分析有些問題在分析施噴霧滴型態之前就必須先行解決，影像擷取系

統通常會在霧滴和背景間產生一灰色地帶，因此當影像轉換為二元化形式時，霧滴大小會依據分辨白色和黑色分界線的灰色值而改變。另一問題是，收集器的背景可能在整個影像面積內並非均勻，這通常在使用葉片收集霧滴時會發生，不良的打光也會造成背景的變異。有些軟體能夠量測影像區內所有點的霧滴和背景之差異，並將此差異修正為相同。施噴量很大時，會產生很多霧滴，覆蓋面太大時，霧滴將可能重疊，如此要精確量測出霧滴大小將不太可能。一些軟體程式可以修正霧滴的重疊，但再使用時必須小心。最小霧滴的量測值是在影像處理時必須做選擇，霧滴愈小則易消失，亦即霧滴內的追蹤劑少到無法和背景區分。假如選擇較高解析度，能夠量測較小的霧滴，但量測相同霧滴數會增加影像分析的數量。在二元化顯示小霧滴通常需要將灰色分界線設定接近於背景，如此可能使背景被誤認為霧滴而導致霧滴計數的誤差。

影像分析的最高原則是擷取高品質的影像，不論多好的影像處理程式，都不可能從不良的影像得到好的數據，花時間在擷取高品質的影像比修補不良影像會有較佳的效用。

四、討論與結論

在作物蟲害防治上，施噴沉積附著型態是非常重要，尤其在減少農藥使用量上更是如此，少量農藥的有效使用是需要對特定蟲害在株叢棲息地上有最多的施噴。在含有蟲害的株叢特定部分的施噴沉積附著型態，對更進一步減少農藥需求量是一個關鍵，使用生物控制物質在蟲害防治介質的附著上或許需要更精確。

影像分析對施噴沉積附著分析的應用，可以強化科學家在量測和定義施噴型態的能力，在確定沉積附著型態上，這是最有效的第一步驟，對不同的蟲害、農藥和作物，最佳的施噴型態似乎不同，然而我們希望對於有相似取食與棲息地特徵的蟲害，和相似反應的農藥，其較佳施噴型態類似。同時我們必須設計噴霧器對不同的作物和農藥實行施噴，具有不同覆蓋形狀樹枝的強度與彈性等，將需要對噴霧器和噴灑點做修正，以便有最好的施噴附著效率。

DRIFT MEASUREMENT : METHODS AND TECHNIQUES

R.D. Fox, R.C. Derksen, R.D. Brazee, H. E. Ozkan [1]

ABSTRACT

Spray droplet size, droplet release height, wind speed and other factors affect spray drift. Standards or guidelines for measuring drift have been written by the US Environmental Protection Agency, American Society of Agricultural Engineers, Spray Drift Task Force, and the Braunschweig Federal Biological Research Center in Germany. Spray collectors of many types have been used. Ground (sedimentation) deposits collectors include: filter paper, alpha cellulose paper, water sensitive paper, glass slides, plastic sheets of various types, and metal plates placed horizontal. Airborne spray collectors include: vertically mounted sheets of paper or other flat collectors, string, plastic pot scrubbers, pipe cleaners, hair curlers, and on filters in air samplers. Several types of tracer have been used to simulate sprayed pesticides. These include: metal salts, fluorescent materials, pesticides, or food coloring. Examples of several studies of drift measurement techniques and results are presented for ground boom sprayers, orchard air-blast sprayers, and aerial spraying. Ground (sedimentation) deposits decrease rapidly as downwind distance increases, usually becoming less than 1% of applied by 20 m downwind. Airborne spray flux does not decrease as fast as ground deposits, but, in addition to deposition on the ground, the spray droplets tend to mix vertically and, in this way, become less concentrated as downwind distance increases. Deposits on active airborne spray collectors usually become less than 1% of applied by 50 to 100 m downwind, depending on the sprayed canopy and wind conditions.

INTRODUCTION

The drift of spray out of the intended swath has been a concern ever since a farmer sprayed a grain field with 2,4-D and discovered the field was upwind of his wife's tomato patch. Scientists have been measuring drift from boom, aerial, and air-blast sprayers for the past 40 years. Most of the factors affecting drift have been determined. Current research is aimed at developing equipment and practices that will minimize drift while still providing adequate pest control. Many scientific and popular articles have been written on drift measurements and control. Articles included in this discussion were selected because they were considered good examples of drift measurement experiments. Studies of drift while spraying with ground boom sprayers, orchard air-blast sprayers, and, to a lessor extent, aircraft spraying are discussed. No attempt was made to include studies on the movement of volatilized chemicals out of the sprayed region.

Most topics will be covered by citing pertinent literature wherein scientists have

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conducted experiments and theoretical studies that improve our understanding of these problems. Several relevant books on these topics are available. Matthews and Hislop (1993) discuss all types of spraying, including spray droplet production, drift measurement, etc. Pompe and Holterman (1992) provide a good review of literature on pesticide application, including both air-assisted sleeve boom sprayers and air-blast tree and vineyard sprayers. They provide one chapter with a good discussion of spray drift.

Factors affecting drift

Ozkan (1991) discusses factors important in controlling drift from boom sprayers, while Elliott and Wilson (1983) describe drift problems from the standpoint of herbicide application. The principles they present and their discussions of all factors important to drift are common to most spray application methods. Other references are listed at the end of this article.

One factor effecting spray drift is wind velocity and direction, although the size and density of an orchard canopy may lessen wind effects on ground deposits close to the downwind edge. Another key factor is the release height of sprayed droplets. Air jets may transport droplets well above the canopy top where droplets can become entrained in air currents and dispersed higher. Spray droplet size is also an important factor in spray drift. In general, larger droplets are not carried around plant canopy structures but impact the plant, and if they are not deposited, they rapidly fall to the ground. Driftable droplets (droplets less than 150 μm diameter) may be carried greater distances before they settle to the ground, and in suitable conditions may evaporate, leaving particles of active ingredient and formulation that can be transported long distances.

Bache and Johnstone (1992) develop relationships between droplets, their transport by air currents, and deposition on plant materials and other collectors. High air temperatures and low humidity will increase the evaporation rate and may affect drift patterns. Atmospheric stability may be a factor under some conditions. Very stable conditions (with a strong temperature inversion), with low wind velocities can create conditions where a spray cloud may remain airborne and, when air currents appear, spray may be deposited in larger doses at distances from the spray site greater than normally expected. These large concentrations may occur in any direction from the spray site. Sprayer operators have key roles in reducing spray drift, through proper sprayer preparation and in accounting for sensitive regions near the application site.

The objective of this paper is to review and to provide information about current research on spray drift measurement techniques.

DRIFT MEASUREMENT GUIDELINES AND STANDARDS

The U. S. Environmental Protection Agency (EPA) established guidelines for measuring drift for agricultural chemical manufacturers who were directed to conduct drift studies as part of the registration process (USEPA, 1984, or later updates). These guidelines define where and how many collection points must be used to provide sufficient data for EPA to evaluate drift deposit data.

The Spray Drift Task Force is a consortium of 38 agricultural chemical

companies formed to provide the USEPA with spray drift data. They conducted laboratory and field tests of physical properties of typical spray mixtures, measured drop size spectra for a range of nozzles and spray properties, and measured drift from aerial, ground, airblast and chemigation applications in field trials (SDTF, 1994, 1997a, b, c, d, Hewitt, 1998 and many others). The aim of these studies was to show that drift is not dependent on the active material in the sprayed chemical, but on the physical properties of the formulation and the method of application, environmental conditions, and crop canopy conditions during application. These studies were conducted under Good Laboratory Practices (GLP) guidelines, which is necessary for registration data. Most of the SDTF data was similar to results from studies conducted by other scientists, but these data have undergone an intensive review process to meet USEPA requirements. The SDTF and EPA are developing drift models for each method of application (ground, aerial, airblast and chemigation) which will be used to set regulatory rules and label requirements for application.

The American Society of Agricultural Engineers (ASAE) has recently adopted a standard for conducting spray drift studies (ASAE, 1998). It provides guidelines on drift collector location, site recommendations, meteorological measurements, etc. for drift studies.

In Germany, federal, university, and industry scientists developed an exact set of measurement protocols for ground, orchard, and hops spray drift studies (Ganzelmeier, et al., 1992.) These guidelines specify the size of the area to be sprayed and minimum requirements for number of collectors and collector location for each type of application, for both sedimentation and airborne spray. Location and type of meteorological instruments are also specified. In general these guidelines place many collectors within 30 m of the sprayed area (hops require collectors up to 100 m downwind). No collectors were required beyond these specified downwind distances.

Arvidsson (1997) tested several methods for measuring drift from field sprayers, evaluated the relative importance of factors in drift, and suggested a standard method for measuring drift from boom sprayers.

DRIFT COLLECTORS

Ground collectors

Spray falling to the ground (sedimentation) can be captured on any flat surface. While leaves of the sprayed plants are probably the best collectors if plant foliage is the intended target of the spray, most experiments use smooth flat sheets of some type, because they are easier to handle than leaves. In most cases, drift is measured for regulatory purposes, so the worst case is selected for testing. Thus, for ground spraying, tilled soil or closely mowed grass field is selected as the spray site. The assumption is that spraying any extensive plant canopy will produce less drift than spraying short grass. Studies have found that, outside of the spray swath, vertical surfaces usually collect more spray than horizontal surfaces; therefore, spray sediment collectors should be as horizontal as possible. Nearly any collector that is used for collecting deposit with a spray swath can also be used for collecting spray deposits downwind from the sprayed area. Typical collectors include: plastic sheets; paper sheets, including filter paper, alpha cellulose paper, and water or oil sensitive paper; kromekote cards; strings or other cords or lines; metal or glass plates; petri dishes, etc.

Airborne spray collectors

Passive collectors include most of the collectors used for ground or sediment deposits. Further downwind for the sprayed area, large droplets have deposited on the ground, so the airborne droplets tend to be smaller. In these regions, droplets are transported by air currents and may follow the air streamlines as they are deflected around large buff objects such as vertical flat plate collectors. Usually collectors with collection surfaces of the same order of magnitude as the spray droplets being collected have the highest collection efficiency. We have begun to use nylon screen to collect airborne spray. In Europe a popular collector is pipe cleaners. In some German experiments, plastic pot scrubbers were used. Hair curler brushes, combs and other objects with many small diameter collectors have been tried. Because droplet collection efficiency on a collector depends on droplet size and droplet velocity, it is difficult to predict collection efficiency for a spray cloud composed of a spectrum of droplet sizes being carried by air currents which change direction and velocity frequently due to air turbulence. Thus, it is difficult to define what the collection values mean, or to compare airborne spray deposits from one treatment to another.

Active spray collectors include instruments such as rotorods, high-volume air samplers, personal air samplers, cascade impactors, electrostatic samplers, and other types of samplers that use a blower to draw sample air through a filter or collector matrix that removes small particles or absorbs chemical tracers.

An accurate measure of airborne spray requires active collectors to be isokinetic. This implies that samplers must face directly into the wind and must draw the same amount of air through the collector filter as passes a similar area outside the sampler. Such collectors are difficult to construct, although some commercial units are available. Properly operated rotorods are considered isokinetic.

Tracer materials

The best tracers are probably the actual pesticide formulations used for pest control. However analyzing for active ingredients is usually expensive and workers conducting drift experiments are exposed to pesticides. Therefore, in most cases, a tracer material is used to simulate the actual pesticide. Some commonly used tracers include: metallic compounds containing copper, manganese, etc., food coloring, fluorescent materials and salt solutions. An ideal tracer should be: soluble in water, or at least formulated to disperse easily in water; easy to remove (wash) from collectors materials with commonly used solvents such as water or alcohol; visible when dry (such as some fluorescent tracers) so deposit patterns can be observed; stable from spraying to analysis (some fluorescent tracers degrade…lose florescent intensity…when exposed to sunlight); detectable at low concentrations by inexpensive instruments; and safe for workers.

For drift studies, where spray deposits 200 m downwind are being measured, fluorescent tracers are often used because they can be detected at concentrations as low as a few parts per billion. However, most fluorescent tracers tend to degrade in sunlight, which must be considered during use.

Sprayed droplet size is an important factor in the amount of spray drift and the formulation of some fluorescent tracers (and other tracers) may contain surfactants or other adjuvants that affect the sprayed droplet spectrum. All tracers should be tested before use to determine characteristics important to the spray, drift, collector and

analysis systems.

MEASURING DRIFT FROM GROUND BOOM SPRAYERS FIELD EXPERIMENTS

Many field and laboratory experiments have been conducted to measure the relationship between drift amount and distance and spray factors important to drift. This has not proved to be easy. There are great variations in spray deposit, in wind and atmospheric stability conditions and in crop canopies. Thus, even with many replications of experiments that require many deposit samples, statistical significance among variables is not often achieved and many times definite relationships are not obvious. Bode et al. (1976) reported on a series of experiments using the dual-tracer technique to compare two boom sprayer systems with each pass. Dual spraying systems (two tanks, pumps, spray booms, etc.) have worked well in experiments with ground and aerial spraying when the ground surface is the target. Dual application is not as well suited to orchard spraying where an air jet is a critical component of the spray delivery system and the target is a vertical wall. Dual systems allow a 'standard' spray system to be used with all treatments of the test variables spray systems. Wind and other climatic factors change from one test to another. Therefore, paired sprayer systems provide the possibility of covariant analysis to account for background variability. They used statistical methods to identify the most important factors (from 5 climatic, 4 spraying system and 6 combinations) affecting measured spray drift deposit and expected ground deposit beyond 2.4 m from the edge of the field, assuming a field 400 m wide was sprayed. These results are shown in Table 1. Significant factors affecting these measures of downwind deposit were boom height, wind, liquid spray volume and if a 400 m wide strip were sprayed, the amount of Nalco-Trol drift retardant was most significant. The F-values shown are a measure of the relative significance of each factor. Nozzle type was not included as a factor in the statistical analysis because not enough trials were made.

Maybank et al. (1978) is one of a series of articles on drift published by these Canadian researchers. In this study they measured ground and airborne spray deposits for boom sprayers equipped with several nozzle types and for aerial applications with wind speeds from 1 to 10 m/s. Table 2 displays results for a few of their spray trials; initial off-swath deposit is average ground deposits in the first 5 m downwind, initial drift is the average airborne spray between 0.3 and 3 m heights at 5 m downwind. They also measured droplet size of ground deposits on photographic paper and airborne spray with cascade impactors. In Table 2 we see that more spray is airborne at 5 m than was deposited on the ground in the first 5 m downwind of the spray swath. Airborne droplet size was much less than droplets collected in the swath.

Table 1. Factors affecting downwind drift (Nozzle type not included). Adapted from Bode et al. (1976).

Factors considered in analysis	Order of importance in explaining spray drift deposit	F value	Order of importance in explaining drift beyond 2.4 m, if 400 m were sprayed.	F value
Wind speed	Boom Height	9.92	Concentration of thickener	12.85
Relative humidity	(Boom Height)(Wind)	9.65	Wind speed	6.11
Temperature	Spray application volume	7.48	Boom height	4.89
Atmospheric pressure	Wind	7.10	Concentration of thickener/Wind	4.55
Richardson No. (stability)	RH	4.12	(Boom height)(Wind)	3.99
Boom height (17 and 23 in.)	(Wind)(Richardson No.)	3.90	RH	3.90
Spray application volume	(Wind)(Nozzle Press.)	2.80	Temperature/RH	3.26
Nozzle pressure	Atmospheric pressure	2.62	Atmospheric pressure	2.60
Concentration of thickener	Concentration of thickener	1.50	(Temp)(Wind)/(RH)	2.38
6 other combinations of these 9 factors	Nozzle pressure	0.28	Temperature	0.51

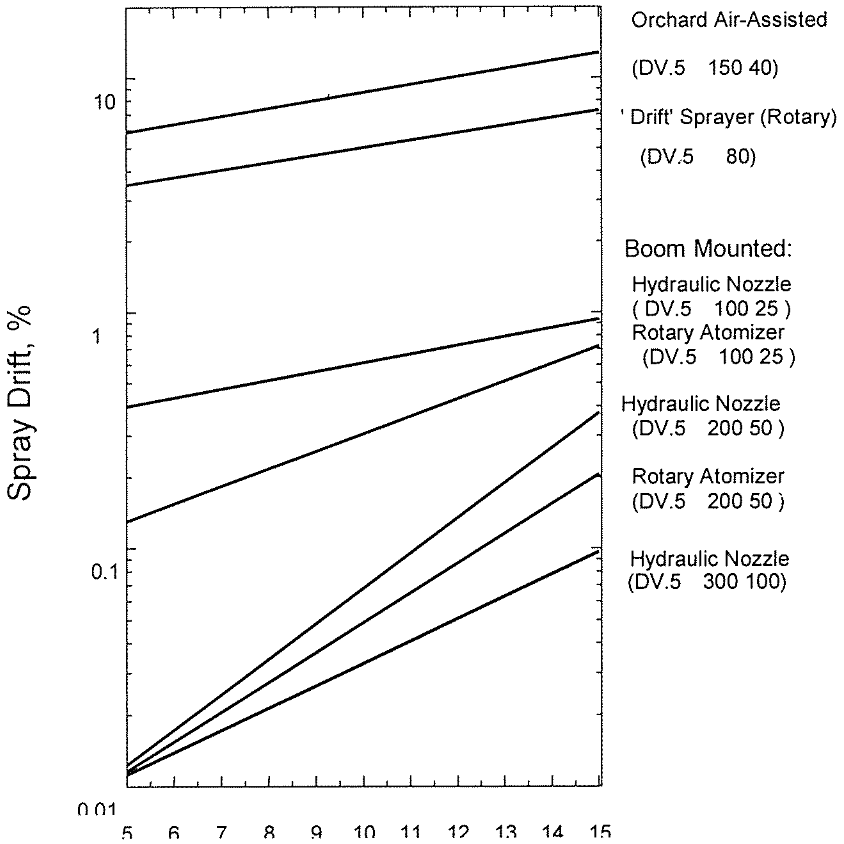
Threadgill and Smith (1975) measured drift of controlled-sized drops (27, 53, 100, 150, and 200 μm) on 4 horizontal targets between 1 and 8 m downwind and 4 vertical targets between 0.8 and 5.3 m above 0.4 m tall cotton. They used statistical analysis and found that the most significant factors affecting total deposits on downwind targets were stability ratio and drop size. They found that as atmospheric stability increased, the potential of sprays to drift decreased. While this may seem to contradict results cited earlier, we should note that they measured both ground and airborne spray deposits, whereas in some other studies, ground deposits only were assessed with small droplets. They did not measure differences in drift when using tank mixes with different specific gravities. In this study, increased wind speed resulted in less drift, but it was concluded that wind speed and stability were closely related and wind-speed effects could not be completely separated.

Table 2. Summary of deposit and initial drift recoveries for various windspeeds and sprayer characteristics. Adapted from Maybank et al. (1978).

Trial type nozzle, pressure, kPa	Windspeed at 2 m ht m/s	Swath deposit % of applied	Off-swath deposit % of applied	Drift, airborne % of applied	Volume median diameter, µm	
					swath	drift
Ground 8002,138	2.4 3.8 6.1	90 140 83	0.4 0.9 1.1	0.6 1.2 1.6	600 590 650	13 15 15
Ground 65015,172	2.6 10.0	106 99	0.7 3.5	0.9 4.7	600 580	14 20
Ground 650067,276	4.6	94	2.4	4.8	440	15
Ground 8002LP,103	4.6	106	0.7	0.6	860	17
Ground thickener	4.6	107	0.5	0.2	1400	11
Spracoupe	1.1 6.0	93 82	3.4 4.1	5.0 15.1	240 260	20 10
Aircraft	2.1 4.1	61 54	6.1 8.0	14.8 31.3	280 220	70 100

Payne et al. (1988) tried to estimate the required width of buffer zones around lakes when spraying permethrin with a knapsack mistblower (about 50 µm $D_{V0.5}$). They report that the worst case for drift deposits is when spraying in light but not calm conditions, with a stable boundary-layer, low relative humidity, and high air temperature.

Gilbert and Bell (1988) describe a system of collectors they have developed to measure airborne spray and ground deposits downwind of a spray site. Figure 1 is a plot of expected airborne spray drift for several spraying systems for a range of wind speeds. These results are based on a series of experiments they conducted over several years. This figure provides a nice comparison of airborne drift amounts produced by several boom sprayer systems and an air-blast system.



SDTF (1997d) conducted field trials with dual boom ground sprayers. When a field 366 m wide was sprayed in a 4.5 m/s cross wind, about 99.9 % of the spray remained in the sprayed area.

Figure 1. Airborne spray drift at 8 m downwind as % of applied spray vs. wind speed; adapted from Gilbert & Bell, 1988.

DRIFT OF DROPLETS IN WIND TUNNEL EXPERIMENTS

Reichard et al. (1992a,1992b) measured the displacement of individual droplets aimed downward in uniform air flow in a wind tunnel and found these values were nearly equal to droplet trajectories predicted by a flow simulation program. They then used the flow simulation program to computed droplet displacements for a range of droplet sizes and initial velocities, release height, wind speed, and relative humidity. Figure 2 is a plot of the predicted effect of wind velocity on the mean drift of 70 to 200 μm droplets. In this simplified spraying system, displacement distance is directly related to the time droplets require to reach the ground and wind speed. Droplet displacement may not be a large problem when herbicide is applied to a section of wheat, but it is a concern when insecticide is applied by a single nozzle over a row of cabbages that are 0.2 m wide, with 0.75 m between rows.

Figure 3 shows that raising the nozzle discharge height increases droplet displacement. Under some conditions, such as a stationary nozzle, the entire spray pattern may respond as a unit, and individual droplets within the pattern may be insulated from the effects of external forces such as air currents.

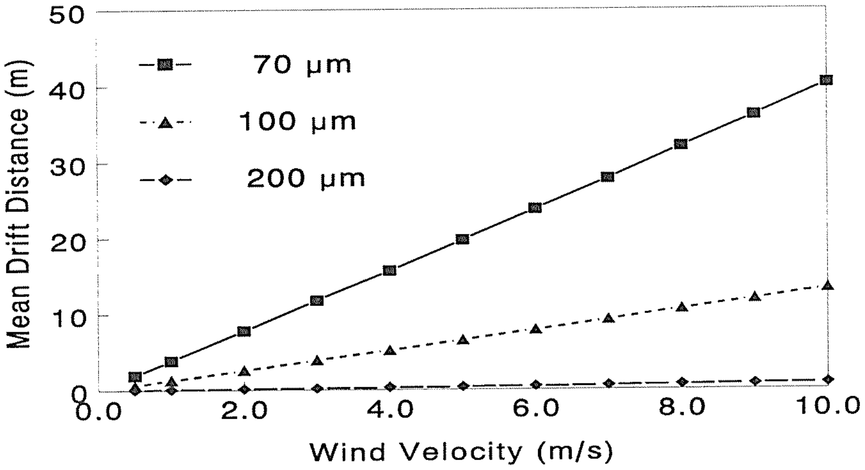


Figure 2. Effect of wind on mean drift distance of droplets directed downward at 20 m/s from a height of 0.5 m.

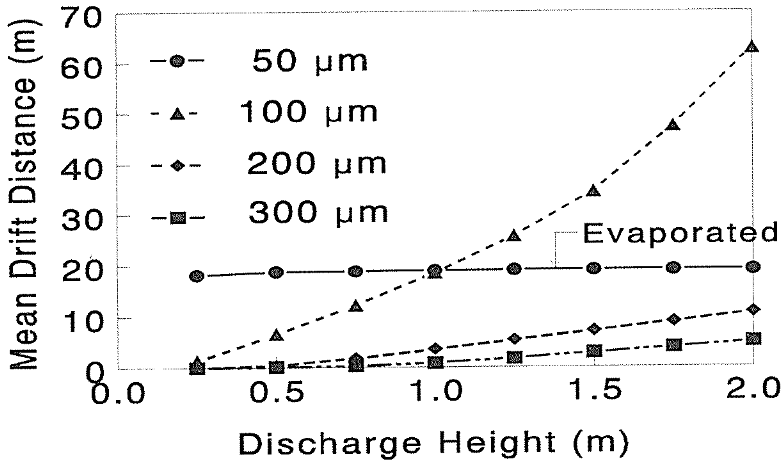


Figure 3. Effect of discharge height on mean drift distance of droplets directed downward at 20 m/s into a 2 m/s wind.

DRIFT FROM TREE AND VINEYARD SPRAYERS

Drift measurements

Measuring drift from spraying orchards and vineyards with air-blast sprayers is also a difficult problem. Constantly changing winds, and canopy movement result in great variability in deposits at collection sites. Other key factors that lead to variation in results are the type of collector used (especially for airborne spray), the tracer used, sprayer operating conditions, number of rows sprayed and crop canopy structure. In the past few years several groups have made measurements of drift from spraying fruit trees; some of their results are summarized here.

Parkin and Meritt (1988) discussed advantages and disadvantages of several methods of collecting drift samples. They reviewed impaction theory and the effect of droplet size, target size and type and wind speed on collection efficiency of the sampling methods. Finally, they discuss impaction and droplet drift models and show data to demonstrate the major points in the presentation. Walklate (1989) discusses meteorological measurements made during a drift experiment and presents equations to calculate relevant parameters to describe ambient conditions that may affect spray drift.

MacCollom et al. (1986) sprayed carbaryl and captan on 6-m tall apple trees with aircraft and with two orchard air-blast sprayers and compared off-target drift. They found more drift from aircraft than from air-blast sprayers and that a temperature inversion resulted in more drift even with a 2% slope of the land. Results of measured downwind ground deposits are shown in Figure 4 along with results from several other studies. Their measured deposits were about 10 times greater than ground deposits measured by other studies.

Riley and Wiesner (1990) measured off-target spray losses resulting from applying pesticide on 6-m tall trees with an air-assisted sprayer. They measured number and size of droplets deposited on ground and airborne spray collectors. Rotorods and wires up to 11 m elevation were used to sample airborne spray. They found that both number and size of droplets decreased rapidly with increased distance downwind. They developed regression equations that can be used to predict worst case deposits from multiple row applications. Results of their measurements of ground deposits are shown in Figure 4.

Fox et al. (1990, 1993a,b, 1994) assayed ground deposits and airborne spray concentrations downwind from air-blast spray applications to the outside row of an apple orchard. They found that ground deposits at 61m downwind were about 1/250 deposits near the tree row. Beyond 30 m downwind ground deposits were about the same when spraying without trees or through a tree row. Beyond 61 m downwind, airborne spray samples were about 10 times greater than ground deposits based on deposit per unit area of the collector. Ground deposits from these studies have been combined and are shown in Figure 4.

Ganzelmeier et al. (1992,1993,1995) developed a standard method for measuring drift from field and orchard sprayers. They reported 32 trials with early-season orchard spraying and 31 trials with late-season orchard spraying. The trials were conducted by several industry, university and government laboratories with different orchards and sprayers, but with standardized procedures. They reported ground deposits up to only

30 m downwind. Airborne spray was collected on plastic pot scrubbers, but because of uncertainty about collection efficiency due to variation in wind velocity, droplet size and other factors, they could not define what was measured, and therefore no airborne data were reported. They used a 95-percentile method to represent the expected worse case of spray drift. This procedure provided a weighted maximum, which may better represent the entire data set than just a few extreme values measured in one or two trials. These results are also shown in Figure 4.

May et al. (1994) measured drift downwind from a mature apple orchard, sprayed with four sprayers. All sprayers simultaneously sprayed twelve rows (5-m spacing). Sequential and cumulative samplers were used to collect airborne spray at 2-m elevation and ground deposits at 82 and 164 m from the orchard. One conventional axial fan sprayer and 3 tower sprayers were used. All three tower sprayers produced less airborne spray and ground deposits than the conventional sprayer. These results have been combined and are plotted in Figure 4.

The effect of tracer, sprayer type, spray operating conditions (sprayed droplet size, air jet characteristics, travel speed, number of rows sprayed, etc), size of the orchard upwind from the sprayed portion, wind velocity, atmospheric stability, type of collector and other factors have been ignored. Ground deposits were combined for all trials found for each of the treatments shown in the legend.

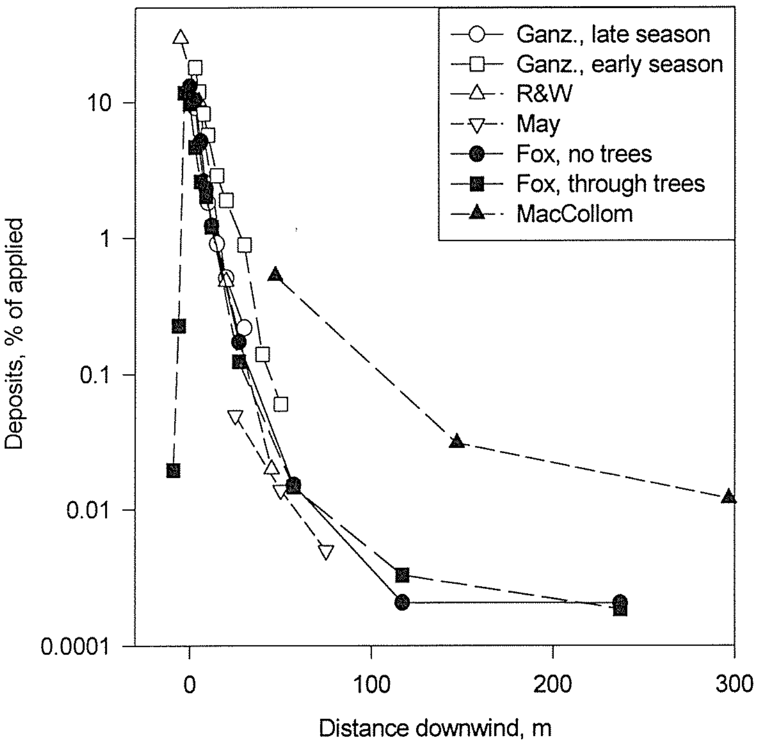


Figure 4. Ground deposits downwind from orchard spraying; a summary of several studies.

Airborne spray deposits measured downwind from sprayed orchards are shown in Figure 5. Active collectors such as high volume air samplers usually collect more spray material than passive samplers such as string, screen, or wire. If Figure 5 is compared to Figure 4, we see that airborne spray amounts decrease as a slower rate with increased distance than do ground deposits.

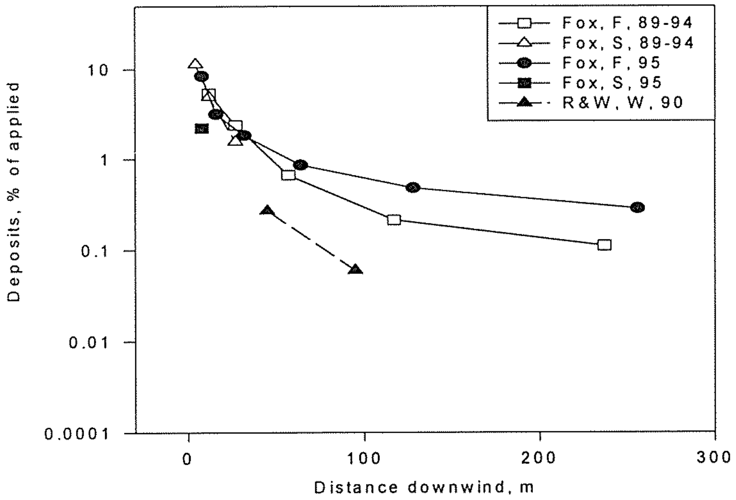


Figure 5. Airborne spray deposits downwind from orchard spraying; a summary of several studies. Legend symbols are: F – high volume air sampler filters; S – string; Sc – Screen; W – wire.

Xu et al. (1997) compared results predicted with a spray penetration model they developed earlier with airborne spray deposits 5 m downwind from a tree row sprayed with an orchard sprayer. Measured deposit profiles agree reasonably well with predicted deposit profiles. Greater travel speed reduced the amount of spray collected downwind from the tree row.

The Spray Drift Task Force (SDTF) (1998b) conducted extensive measurements of drift from orchard and vineyard spraying. These measurements were conducted using Good Laboratory Practices (GLP) and is probably the most comprehensive set of drift measurements from orchard spray trials conducted to date. They found that about 96% of the total spray applied to the last six rows of an orchard stayed within the orchard area. As expected, spraying tall trees resulted in more spray deposits downwind from the orchard. They found that spray collected on vertical strings decreased greatly as spray moved from two to five rows downwind from the sprayed row, i.e., downwind tree rows acted as a filter for spray passing through the sprayed trees.

Spraying of dormant trees

Many fruit trees are sprayed when the trees are dormant. We have measured leaf area indices (LAI) of about 3 for semi-dwarf trees with foliage and about 0.6 for dormant trees. Thus there is a much smaller target for spray during dormant applications. Herrington et al. (1981) found that only about 10% of applied spray was deposited on the tree parts during dormant application. The SDTF (1998b) also found that spraying dormant trees resulted in greatly increased downwind deposits compared to spraying trees in full foliage.

Steinke et al. (1992) sprayed dormant almond trees with axial flow and cross-flow sprayers and a helicopter. They measured deposit on tree twigs, downwind drift

and insect control. They found a strong correlation between pesticide deposit and insect activity - i.e., more deposit resulted in less insect activity. They measured increased deposit throughout the tree with the cross-flow sprayer as compared to both the axial flow sprayer and the helicopter. Downwind deposits on ground collectors were less than on airborne spray collectors. The cross-flow sprayer produced the greatest airborne spray amounts.

Walklate (1992) developed a random walk atmospheric diffusion model to predict spray movement from an axial flow fan orchard sprayer. Drift simulations agreed well with measured drift over stubble and orchard canopies.

AERIAL APPLICATION

Ware et al. (1969b) compared a mist blower applying 28 L/ha with aircraft spraying 65L/ha on alfalfa. They found that the mist blower produced greater deposits of methoxychlor on glass plates, in air scrubbers, and on alfalfa than the aircraft at distances from 50 to 800 m downwind.

Yates et al. (1974) is one on many reports on drift from aerial applications by this research group. In this study they measured over 13 times as much deposit at 400 m downwind when spraying during very stable than for neutral atmospheric conditions. They also collected 5.5 times as much residue at 800 m downwind when spraying with nozzles that produced small droplets than when using nozzles producing larger drops.

Yates et al. (1978) compared ground sprayers using 8003 and low-pressure deflector type nozzles with fixed wing and helicopter aircraft spraying roundup. At stations less than 91-m downwind, drift from the low-pressure deflector nozzle 10 KGF was 100 times less than when spraying with the 8003 nozzle. Use of a thickener reduced drift from the 8003 nozzle by 1.5 to 2 times. Drift from the helicopter with low-pressure micro-jet nozzles was nearly as low as with the deflector nozzle, however, drift from the helicopter with jet-type nozzles (D-4) was the largest for all spray systems. The fixed wing aircraft with jet-type (D-6) nozzles produced drift deposits greater than the 8003 treatments for downwind distances up to 122 m. They collected about 10 times as much deposit on high-volume air sampler filters (airborne spray) as they did on Mylar sheets on the ground.

Salyani and Cromwell (1992) compared ground and airborne spray deposits resulting from spraying an orange grove with an orchard air sprayer, a fixed wing aircraft, and a helicopter. High and low liquid application rates were applied with the orchard air sprayer. Averaged over all downwind locations, greatest airborne spray deposit and the least ground deposit was produced by the orchard sprayer applying the low liquid volume, but there was not significant differences between drift from aerial and ground spraying.

The SDTF (1997a) conducted a series of experiments using pesticide tracers and found downwind deposit amounts similar to those measured by other studies. When spraying a 55 m wide strip of ground with 90 spray trials, they found the average volume of spray deposited within the sprayed area, with a 4.5 m/s cross wind, was 92%.

There have been many studies of spray dispersion and deposit by the U.S. Forest Service and in Canada. There are now available at least two commercial programs that predict spray dispersion and deposition when spraying forests with aircraft, FSCBG from

Continuum Dynamics (Bilanin et al., 1989) and a model by Picot of New Brunswick (Picot et al. (1986).

SUMMARY

Measuring spray drift generally requires a large staff because several hundred collectors must be changed after each spray treatment. Owing to the high degree of variability in application and drift processes, many replications are necessary and even then it is difficult to obtain statistically significant differences among treatments. Thus, experiments are expensive to conduct and many variables can change during their course. Several downwind deposit models for aircraft, ground and orchard spraying are under development and should be available in the next few years. These models, when properly validated, should guide drift research by providing a framework for individual drift studies. Some variables can be tested with the models and actual field trials can be used to verify parameter variations that are questionable.

Many different protocols have been used for drift experiments. Collectors, tracers, collector locations, application procedures, and analysis techniques have varied widely. With the development of the European Union, standard test procedures for sprayer testing, including measuring deposits on crops and drift, are being developed. It is likely that this will lead to more standardization among all of the rest of the world, including the U.S.A. When standard methods for measuring drift are adapted in many locations, then a large amount of data should become available to define differences due to more subtle factors, such as terrain, valley wind effects, etc.

After reviewing many studies on measuring drift from many different types of sprayers, we can summarize the results as follows:

Ground boom sprayers: total drift is about 5% of applied spray, with about half of this falling on the ground in the first 10 m downwind; ground deposits fall off to about 1/10000 applied by 90 m. Airborne spray flux at 10 m downwind and at 2 m height is about 2 to 10 times ground deposits at the same downwind distance (on an area basis). Reducing the percentage of spray in the "driftable" size range (less than about 100 μm diameter) by changing nozzle type, lowering nozzle pressure, using adjuvants, etc. usually reduces drift; for example, adding a thickener usually reduces ground deposits in the first 10 m to 0.5 to 0.75 of deposits using water. Lowering of boom height also reduces drift.

Meteorological factors: temperature and relative humidity affect the evaporation rate of droplets, these factors will probably not have much effect on deposit in the first 10 m, but may affect long range dispersion of droplets. Wind speed is an important factor; increased wind speed will increase swath displacement and the total amount of spray carried out of the swath. However, increased wind speed may reduce ground deposits immediately downwind of the displaced swath.

Ground deposits downwind from a sprayed trees and vineyards decrease rapidly with increasing distance downwind. Beyond 30 m from the edge of the sprayed area, ground deposits are usually less than 0.3% of the applied amount. Airborne spray deposits decrease less with increased distance downwind than ground deposits. Beyond 30 m downwind from the edge of orchards, airborne deposits are usually less than 3% of the applied amount and airborne spray concentration is nearly uniform from

the ground to about 10 m.

Aerial application results in about 5 to 10 times more ground deposit within 10 m and 5 to 10 times more airborne spray flux than ground boom spraying. Air-blast sprayers usually produce less ground deposit and airborne spray flux than aircraft spraying, however under certain conditions, such as using low volumes with small spray droplets, air-blast sprayers may produce more drift than aerial.

This review has covered the movement of spray out of the intended swath, but does not include consideration of how changes in the spray application system to reduce drift will change nozzle pattern, plant coverage or, the objective of spraying, biological efficacy.

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量測噴藥飄積現象的方法與技術

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摘要

施噴霧粒大小、霧粒釋放高度、風速和其他因子影響噴藥飄積。量測飄積的標準或指導原則已由美國環保署、美國農工學會、噴藥飄積特遣組織（Spray Drift Task Force）及德國 Braunschweig 聯邦生物研究中心訂定。許多型式的噴霧收集器被使用過。地面沈積收集器包括：濾紙、阿法纖維質紙、水試紙、玻片、多樣的塑膠片、及金屬片水平放置。滯空式噴霧（airborne spray）收集器包括：垂直吊掛的紙張或其他平板收集器、細繩、塑膠塑刷（plastic pot scrubbers）管子清潔器、捲髮器、和空氣採樣過濾器等。數種追蹤器曾被用來模擬施噴過的殺蟲劑。這些包括：金屬鹽、螢光劑、殺蟲劑、或食用色素。地面噴桿噴藥機具，果園鼓風式噴霧機和空中噴藥的飄積量測技術和結果之數個研究範例在本文中介紹。地面沈積隨下風距離增加而迅速降低，通常約在下風 20 公尺處沈積變為不到施噴量之 1%。滯空式流量之減少不如地面沈積來的快，但是，除了沈積地面之外，施噴霧粒趨於垂直混合，如此一來當下風距離增加時濃度變低。在主動式滯空式噴霧收集器中的沈積通常在下風 50 到 100 公尺處少於 1%，依噴霧葉面覆蓋情形和風的狀況而定。

緒論

有位農民在麥田中噴施 2,4-D 時，發現有些藥劑霧粒隨風飄移到下風地帶他太太的番茄園中，造成影響，從此引發了噴藥飄積現象的研究題材。過去四十年間，科學家們一直在量測桿式噴藥、空中噴藥、及鼓風式噴藥等設備造成的霧粒飄積現象，並已找出影響飄積的因素。目前的研究則著重於研發降低飄積現象的設備與方法，對此已有不少的學術性及大眾性報導，都偏重於飄積現象的量測與控制。本文蒐集了一些飄積量測實驗的範例，探討露地桿式噴藥機，果園鼓風噴藥機，以及飛機空中噴藥等，但並不涉及揮發後農藥飄積的研究。

本文討論的題材，都是依科學家實驗結果或理論推導而成的專業文獻為本，使我們更能深入了解這些問題。Matthews 與 Hislop 在 1993 年探討農藥噴

灑的各種狀況，包括噴灑霧粒的形成，飄積現象的量測等。Pompe 與 Holtermam 於 1992 年完成 A 桿式氣輔噴藥及果樹與葡萄園鼓風式噴藥農藥撒佈方面文獻回顧，他們都有專章論及噴藥飄積現象。

影響霧粒飄積的因素：

Ozkan 於 1991 年探討桿式噴藥設備控制飄積現象的重要因素；Elliott 與 Wilson 在 1983 年由噴灑殺草劑的觀點解說飄積現象，他們陳述有關霧粒飄積的原理及各項重要因素與大多數噴灑方法相同。本文末頁尚有許多的文獻可供參考。

雖然防風林或擋風牆有助於降低風力對下風方向的地面噴量影響的效應，風速與風向仍是影響噴藥積的因素之一，另一個關鍵因素是霧粒噴灑的高度，氣流極可能將霧粒吹送越過防風林或牆，使霧粒隨著氣流分散得更高。

噴灑霧粒的大小也是一個影響霧粒飄積重要的因素，一般而言，較大的霧粒會落到植株上而不致飛越植株的屏蔽，如果這些大霧粒不曾停留在枝葉上就會很快的墜落地面。會飄積的霧粒（直徑小於 150μm 的霧粒），在墜落地面之前會被飄送較遠的距離，如果環境比較高溫乾燥，甚至會蒸散成為藥劑活性顆粒而飄送得更遠。

1992 年間，Bache 與 Johnstone 推論出霧粒飄送氣流強度作物葉體附著性及其它附著物之間的關係，高溫低溫的空氣會提高霧粒蒸散率而影響其飄積方式，在特定條件下，氣候的穩定性可能成為影響飄積現象的因素，當風速很低，氣溫急速下降的穩態氣候下，霧化的藥液會滯留空中，待氣流一旦出現，作物面上附著藥劑的劑量將會有過量之虞。所以，噴藥操作人員其實扮演著降低飄積現象的關鍵性角色，只要他能適當的調整使用與噴灑設備，並仔細顧及噴藥區週遭的相關地區。

本文的目的是提供有關目前飄積現象量測技術的研究資訊。

量測飄積現象的規範與標準

美國環保署(EPA)規定農藥廠商在商品註冊時必須繳附相關的飄積研究報告，所以特別為農藥廠商設立量測飄積現象的規範，明訂出飄積試驗中霧粒蒐集的方法與位置，俾能使環保署有充分的數據分析其飄積現象。(USEPA，1984 或修訂版)

噴藥飄積特遣組織(Spray Drift Task Force，SDFT 是美國 38 家農藥製造廠商組成的一個團體，專對美國環保署提供飄積試驗數據。該組織進行實驗室，以檢測各種典型的噴灑液劑的物理性質，量測不同噴頭及噴灑特性下的霧粒大小分佈，並從空中、露地，鼓風及 Chemigation 噴灑作業之田間實驗中量測飄積現象。此類研究的目的為顯示飄積現象，並不與依存於農藥的活性，而是與藥劑的物理性質、噴灑方法、環境條件及作物屏蔽狀況有關。這些研究都是在 Good Laboratory Practices (GLP)規範下進行，使實驗數據能符合商品註冊的需求。STDF 的大多數實驗數據皆能與其它科學家的研究結果相吻合，這些數據都須經歷澈底的檢驗與評估，使能符合美國環保署的要求。美國環保署與 STDF 正在發展各種噴藥方式如（空中、露地，鼓風及 Chemigation）的霧粒飄積模式，用以建立噴藥法規及標示說明。

美國農業工程師協會（ASAE）最近於 1998 年建立研究噴灑飄積的標準。此項標準提供了飄積研究中收集器的放置位置及氣象量測等方面的規範。

在德國，其聯邦政府、大學及產業界的科學家，發展出一整套量測露地、果園及飛機噴藥等霧粒飄積研究的草約，這些規範切確載明對沈降式或滯空式噴藥方式的噴藥區域大小，蒐集器的最低數量。一般而言，這些規範指定蒐集器應放在噴藥區域 30 公尺以內（飛機噴藥則是在下風方向 100 公尺以內），超過這些指定的下風距離，就無須放置蒐集器。

Arvidsson 於 1997 年利用田間噴灑設備測試數種量測飄積的方法，評估各種影響因素的重要性，且對桿式噴藥設備的飄積量測建議出一個表標的方法。

噴灑物粒飄積收集器

地面表型收集器（Ground collectors）

沉降型的噴灑藥物粒落到地表時可由平面收集之。如果作物的葉片是被噴灑的目標物，則葉面堪稱最好的收集器。大部分的實驗都由以各稱平滑的板材作為收集器，因為這種材料比葉片還要容易處理。絕大部分的實驗案例中，飄積現象都是在調整的環境中進行量測，用以測試最糟的情況。因此就露地噴藥而言，常用耕犁過的田區或剪短過的草地作為噴灑區域。如此做法的原因是假設一些稀疏的植株本體會有屏蔽作用因而降低噴藥飄積現象。研究結果顯示噴藥區域外側的鉛垂表面上常較水平表面更能收集到較多的霧粒，因此，對沉降式噴藥而言，收集器應盡量平放。近來在噴藥區域內收集藥滴的器具亦可用於收集隨風飄積的霧粒。典型的收集器應包括下列部分：塑膠片、紙片(包括濾紙、阿法纖維質紙、水性或油性試紙、Kromekote card、細繩或線、金屬)或玻璃版、硬盤等。

滯空式噴霧收集器（airborne spray）

粒徑較大的霧滴會在下風方向墜落地面，而大部份用於沈降式噴藥的收集器都可用為此類噴藥的被動式收集器。由於粒徑較大的霧滴會在下風方向墜落地面，而滯空的霧粒都是較小的顆粒。在滯空是噴藥區內，霧粒會隨著氣流的流線飄送開來，並偏離繞過直立式平板收集器等大型磨光物體。通常，在霧粒收集過程中，若收集器的收集面皆同向排列，會有最高的收集功效。尼龍篩網已被用為滯空式噴灑的霧粒收集器，在歐洲，刷管器常被用為收集器，在德國的一些實驗中，塑膠至的刷罐器也被用於此。捲髮器、梳子以及一些有網枝狀的物品皆被試用為霧粒收集器。由於霧粒收集器的效能取決於霧粒大小及速度，當隨風漂浮的噴灑細霧因空氣亂流而不斷改變速度與方向時，要預測霧粒收集器的收集效能就不是那麼容易了。所以，對滯空式噴藥而言，在不同的作業條件下，很難以相互比較其收集器上的附著量，或是訂出收集量的涵義。

主動性霧粒收集器包括旋轉桿(rotorods)，高容量空氣採樣器，個人用空氣採樣器，翼列式衝擊器，靜電式採樣器，以及其他各種粒徑較大的霧滴會在下風方向處墜落地面，而採樣器等儀器以古風積驅使樣本空氣穿過收集器或過濾器藉此吸附霧粒或化學追蹤劑。若欲精準的量測滯空式噴藥，其霧粒收集器對樣本空氣就須有均等的運動特性。也就是說當樣本空氣流過收集器內的過濾設備時採樣器外方區域同時要有相同的風場，目前雖然已有上市販售的產品，但這種收集器很難構建。仔細操作的旋轉桿（rotorods）可視為具有均等運動特

性的儀器。

追蹤劑材料（Tracer materials）

農藥本身的時化學成分應是最好的追蹤劑，然而，若欲分析這些活性成分含量，通常都是所費不貲，且使執行飄積實驗的人員暴露在農藥之中，所以，有很多案例中會用追蹤劑來模擬實際的農藥。一些常用的追蹤劑包括含有銅、鎂等成分的複合金屬製劑、食用色素、螢光劑及鹽水。理想的追蹤劑應是可溶於水，或是至少很容易在水中飄散開來的製劑；應是很容易從收集器上以水或酒精等滌除的材料；也應是乾後可以顯影的材料（如螢光劑），以便觀察霧粒附著的形式；也應是在分析過程中具有穩定性質（例如有些螢光劑可能因日照分解而降低強度），且在低濃度下亦可使用不很貴重的儀器輕易偵測；更應是安全無害人體的。飄積研究中，噴霧沈積在 200 公尺下風處量測，螢光追蹤劑常被使用，因為他們可偵測濃度低到數個單位/十億。然而大部份的螢光劑在陽光下均會分解，這是使用時必須考慮之處。

噴霧大小對噴霧飄積量是一重要因子，同時某些螢光追蹤劑（或其他追蹤劑）之調配可能含有介面活化劑或其他補助物會影響噴出的霧粒分子。所有追蹤劑均應在使用前接受測試以決定其對噴霧、飄積收集器及分析系統的重要特徵。

地面噴桿噴機具田間試驗之飄積量測

許多田間與實驗室的實驗已經建立起來，以量測飄積量與距離和對飄積重要之施噴因子間的關係。這並不是一件易事。有許多大變數包含在施噴沈積，風和大氣穩定狀態及作物葉生遮蓋等。因此，即使許多試驗要求許多沈積的取樣，變數間之統計差異仍難獲得而且定義的關係並不明顯。Bode 等人（1976）報告一系列的實驗利用雙追蹤器之技術來比較在每一趟施噴的兩組噴桿施噴系統。雙施噴系統（二個藥液桶、泵、噴桿等）在目標為地面時，地面與空中施噴的試驗均十分良好。雙系統不太適合果園噴藥，其中空中噴射頭（jet）為噴灑輸送系統之主零件而且目標為垂直面。雙系統允許一個〝標準〞施噴系統用在試驗變數之所有試驗方法。風和其他試驗因子因實驗而異。因此成對施噴系統提供考慮背景便亦之分散分析的可能性。他們利用統計的方法來定義影響施噴飄積沈積的重要因子（由 5 個氣候、4 個施噴系統和 6 個組合）及超過田邊 2.4 公尺之預期沈積，假設施噴田為 400 公尺寬。結果見表 1。明顯影響這些下

風沈積之量測因子為噴桿高度、風、藥液施噴體積及若施噴 400 公尺寬帶，Nalco-Trol 延遲飄積的量最顯著。表中的 F 值代表每個因子的相對差異的量測。噴嘴的形式不包括在統計分析因子中因為沒有做完足夠的試驗。

Maybank 等人（1978）的論文為一系列的飄積文章由這些加拿大的研究者發表。在此研究中，他們量測附掛不同形式噴嘴的噴桿施噴機具及空中施噴於風速自 1 到 10m/s 地面和空中飄積施噴的沈積。表 2 列出他們施噴試驗之一些結果；初始的行寬外沈積為最初下風 5 公尺處的平均地面沈積，初始飄積則為在下風 5 公尺處 0.3 和 3 公尺間的平均空中飄積施噴量。他們也量測在相紙上地面沈積與瀑布狀的撞擊器（cascade impactors）上滯空式沈積的霧滴大小。在表 2 中可明顯看到噴霧在 5 公尺處滯空式較噴寬內地面沈積為多。滯空式之霧粒較行寬上收集的小。

Threadgill 和 Smith（1975）在下風 1 到 8 公尺處的 4 個水平目標和在 0.8 到 5.3 公尺，高於 0.4 公尺棉花的 4 個垂直目標量測限制大小液滴(27,53,100,150, 和 200 μm）之飄積。他們利用統計的分析發現影響下風目標總沈積量的最顯著因子是穩定比（stability ratio）和霧滴大小。他們發現當大氣穩定度增加時，施噴飄積的趨勢及降低。然而這可能和前面文獻之結果衝突，吾們應注意他們是同時量測地面和滯空式之施噴沈積而其他的則僅針對小霧粒的地面沈積做量測。他們對藥液桶內之混合劑並未量測飄積程度之差異。在此篇研究中，增加風速導致較少的飄積，但是總結風速與穩定度十分相關，同時風-速度之影響不能完全分離。

Payne 等人（1988）嘗試在湖邊使用背負式噴霧器（約 50 μm $D_{v0.5}$）施噴 permethrin 時估算所需緩衝區之寬度。他們報告飄積最差的狀況為施噴於輕但不安定的狀態、穩定的邊緣層低、相對濕度高與高氣溫。

Gilber 和 Bell（1988）描述他們發展之一個收集系統用來在一施噴區的下風處量測滯空式施噴和地面沈積。圖 1 為在一風速範圍內不同噴藥系統的預估滯空式施噴之飄積。這些結果是他們建立多年的一系列試驗成果。這個圖提供很好比較，針對滯空式施噴之飄積量來自數種噴桿噴霧系統和一個鼓風系統。

SDTF（1997d）以雙噴桿地面噴藥系統建立田間試驗。當施噴 366 公尺寬

的田間，橫風速為 4.5m/s，大約有 99.9%施噴保留在施噴面積內。

風洞內的霧粒飄積試驗（DRIFT OF DROPLETS IN WIND TUNNEL EXPERIMENTS）

Reichard 等人（1992a，1992b）在風洞中測量恆風速下單一霧滴瞄準下風處之位移，發現這些值幾乎與流動模擬程式中預測的軌跡相同。因此他們即利用此模擬程式計算霧粒位移針對霧粒大小之範圍與初速、釋放高度、風速，及相對濕度。圖 2 係描繪風速對 70 到 120μm 霧粒的平均飄積之預估影響。在這簡化的噴藥系統中，位移距離直接與霧粒落地之時間與風速相關。霧滴位移在麥田區施用殺草劑時可能不是一個大問題，但是當殺蟲劑以單噴頭施用於甘藍菜的行間，0.2m 寬，0.75m 行間距，時即值得考慮了。

圖 3 顯示出提高噴頭噴灑的高度會增加霧粒的位移，在某些情況下，例如固定噴頭，整個噴灑的型態可能成一單元反應，同時在一型態中的單一霧粒可能由外力之影響，如氣流，而被隔離。

由果樹及葡萄園噴藥器具產生之飄積（DRIFT FROM TREE AND VINEYARD SPRAYERS）

飄積測量（Drift measuyments）

從果園和葡萄園使用鼓風式噴藥機量測飄積也是相當困難。定時改變風速與葉片遮蓋的移動導致在收集區沉積的變異相當大。其他關鍵因子導致結果的異有收集器的種類(尤其是用在滯空式噴藥)，追蹤器之使用，噴具操作之狀況，噴灑之行數及作物葉片遮蓋之結構。過去幾年來，數個團體會測量果樹噴藥的飄積；部份結果在此處做摘要說明。Parkin 和 Meritt（1988）討論數種收集飄積樣本的方法之優缺點。他們也回顧碰撞理論和霧粒大小之影響，目標大小和型態與風速在取樣方法之收集效率等。最後他們討論碰撞和霧粒飄積模型並公佈數據來示範說明主要的觀點。Walklate（1989）討論氣象量測由飄積試驗得到，同時展示方程式用來計算相關參數以描述可能影響噴灑飄積的周遭狀況。

MacCollom 等人(1986)用飛機在 6 公尺高的蘋果樹施 Carbaryl 和 Captan，和兩個果園用的鼓風式噴藥機做偏離目標之飄積比較。他們發現空中噴藥較鼓風式噴藥之飄積大而且逆溫比 2%坡度造成的飄積大。下風處量測的地面沈積

量和其他許多研究之比較繪於圖 4。他們量得的沈積較其他研究高出 10 倍。

Rily 和 Wiesner（1990）利用氣助式（air-assisted）噴藥機噴施殺蟲劑於 6 公尺高之果樹量測其偏離目標之損失量。他們量測霧粒沈積在地面上及在空中飄浮之噴藥收集器中的霧粒數目和大小。高達 11 公尺之滾桿（rotorod）和線用來採取在空中飄浮的霧粒。他們發現下風距離增加霧粒大小及數量均極迅速地下降。他們開發出迴歸方程式用來預測由多行噴藥造成之最差情況。測得的地面沈積結果，見圖 4。

Fox 等人（1990，1993a，b，1994）鼓風式噴藥機在蘋果園的外行噴藥，分析下風處地面沉積和在空中飄浮的施藥濃度。他們發現離下風處 61 公尺之地面沉積量為果樹邊的 1/250。下風處 30 公尺以上地面沉積量與沒有果樹或穿過一行果樹之噴灑結果大約相同。超過 61 公尺下風處，依收集器單位面積之沉積量，在空中飄浮之量比地面約多 10 倍。這些有關地面沉積之研究整合於圖 4 中。

Ganzelmeier 等人（1992，1993，1995）發展出量測由田間與果園噴藥機具產生飄積的標準方法。他們報告在季初果園施藥之 32 個試驗與 31 個季尾試驗。這些試驗由數個公司、大學和政府實驗室利用不同果園與噴藥機具建立而成，但使用標準的程序，他們報告地面沉積只到 30 公尺下風處。空中飄浮霧粒以塑膠瓶刷收集，因為有效收集的不定因子如風速，霧粒大小和其他因子的關係，他們無法定義他們的量測結果，所以沒有報告空中飄積量。他們使用 95 % 之信心程度化表飄積之最差狀態的預測。此程序提供最大加權。可能比只用幾個量測於一或二個試驗之極值較能代表整組數據。結果亦見於圖 4。

May 等人（1994）在成熟的蘋果園中以四種噴藥機具施藥，測量下風飄積。所有噴灑同時覆蓋 12 行（5 公尺行距）。依序和累積取樣用在收集空中飄浮量，高度為 2 公尺，地面沉積收集則在離果園 82 及 164 公尺處。一個傳統軸向風扇噴具 3 個塔式噴藥機在此使用。所有 3 個塔式噴藥機產生的空中飄浮均較傳統式少。結果整合與繪於圖 4 中。

曳引機效率、噴灑器具之型式、噴施作業狀況（噴出之霧粒大小、空氣噴嘴特性、行走速度、噴施行數等），從噴施部份果園的大小、風速、大氣壓的

穩定度，收集器的型態及其他因素均被忽略。所有試驗之地面沈積均顯示於說明圖中。

由噴施過的果園之下風處量得的在滯空式之噴灑沈積會於圖 5 中。主動收集器如高體積之空氣取樣器通常比被動式收集器，如細繩、網或繞線等，收到更多的噴施物質。若圖 5 中和圖 4 比較，在滯空式之噴灑在距離增加時，物力減少之趨勢較地面沈積法來的緩和。

Xu 等人（1997）用他們早期開發出來的噴施穿透模式自一行果樹用果園噴藥機具以在滯空式沈積 5m 下風處預測的結果和果園噴灑機具做比較。量測的沈積區與預測的沈積區有合理的吻合。較高的行進速度可降低下風處從果樹行收集的噴灑量。

噴藥飄積特遣組織（Spray Drift Task Force, SDTF）（1998b）建立自果園和葡萄園噴藥產生飄積的延伸測量。這些量測建立於使用 Good Laboratory Practices（GLP），同時可能是目前最佳、最完整的果園噴藥試驗飄積測量組。他們發現大約有 96%的要亦噴施於果園內的最後六行。一如所料，在果園內噴施高的果樹會導致下風處之噴施沈積。他們發現當噴施作業從下風噴施過的 2 行移到 5 行要亦在垂直捲線上減少許多，也就是說，下風處的樹行在噴過的樹叢中充當濾網。

休眠樹的噴施作業（Spraying of dormant trees）

許多果樹之噴藥是當他們是在休眠時。吾們曾量測半矮株有葉子的樹之葉面積指標（LAI）約等於 3 而對休眠期的樹則為 0.6，因此在休眠應用時噴施目標小許多。Herrington 等人（1981）發現在休眠期間噴施沈積之沈積只有 10%在樹上。SDTF（1998b）亦發現對休眠樹噴施和對滿葉樹的噴施比較下，前者之下風沈積大量增加。

Steinke 等人（1992）以軸流（axial flow）和橫流（cross-flow）噴藥機具及直昇機對休眠的杏樹施噴。他們量測在樹枝的沈積、下風飄積和病蟲害控制。他們發現殺蟲劑沈積量和昆蟲之活動有強烈的關係，也就是說，沈積愈多害蟲即愈少。他們量測增加沈積經由果樹用對流噴灑機具和軸流噴灑機及直昇機做比較。下風沈積，地面收集器少於在滯空式之收集器。橫流噴藥機產生最多滯

空式之霧粒量。

Walklate（1992)開發一個隨機遊走大氣擴散模型來預測噴霧移動從一個果園用軸流風扇噴灑器。飄積模擬與量測果業與斷株的飄積吻合。

空中施噴(AERIAL APPLICATION)

Ware 等人（1969b）在苜蓿草上用吹霧機以 28L/ha 施噴和飛機施噴 65L/ha 做比較。他們發現由下風處 50 到 80 公尺之距離，吹霧機在玻璃盤、空氣刷及苜蓿草上產生甲基氧化氯（methoxychlor）之沈積較飛機施噴為多。

Yates 等人（1974）的報告為空中噴藥造成飄積的其中一篇。在這篇報告中，他們在下風處 400 公尺處測得大氣狀態為穩定下比靜止之下施噴多 13 倍以上的沈積量。他們也以產生霧粒之噴頭施噴下，在下風處 800 公尺處收集比大霧粒噴頭施噴下的殘餘輛多 5.5 倍。

Yates 等人比較了地面施噴器具 8003 和有固定翼的低壓變流型噴嘴與直昇機噴嘴集合。在下風少於 91 公尺處，由低壓變流型噴嘴 10KGF 產生的飄積較 8003 噴嘴少 100 倍。使用一個加濃器（thickener）在 8003 噴嘴可減少飄積 1.5 到 2 倍。使用低壓 micro-jet 噴嘴的直昇機所產生之噴藥飄積幾乎與使用變流型噴嘴者一樣低，然而，由使用 jet-type（D-4）噴嘴的直昇機產生之飄積是所有施噴系統中最大的。固定翼的飛機使用 jet-type（D-6）所產生的飄積沈積對下風距離至 122 公尺較 8003 為多。他們用高體積空中取樣過濾器（滯空式施噴）收集到的沈積大約比以 Mylar 試紙在地面收集多 10 倍。

Salyani 和 Cromwell(1992)在柳橙樹叢中以果園噴藥機具，固定翼飛機和直昇機作地面和空中飄積施噴之沉積比較。高、低施噴藥液比率用於果園空中噴藥機具上。果園噴藥機具以低藥比率施噴產生中等之下風位置，最大的滯空式沉積和最少的地面沉積，但是空中和地面施噴之飄積並無明顯的差異。

SDTF(1997a)建立一系列的實驗使用殺蟲劑近蹤器和發現下風沉積量類似其他研究所測得的結果。當施噴在 55 公尺寬的地面上，用 90 種試品，他們發現在施噴面積內施噴的平均沉積容量在橫風 4.5m/s 下為 92%。

美國森林服務處及加拿大有許多施噴分解與沉積的研究。目前至少有兩個商業軟體針對使用飛機作森林施噴與分解之預測，FSCBG 源自 Continuum Dynamics(Bilanin 等人，1989)及由 New Brunswick 的 Picot 建立一個模型(Picot 等人，1986)

總結（SUMMARY）

量測噴灑飄積通常需求許多人員，因為每完成一次施噴試驗就有上百個收集器需要更換。基於在施噴的高度變化與飄積過程，多次重複性是必要的，即使如此仍然很難在試驗樣品間獲得統計上之差異性。因此，試驗之建立十分昂貴，同時很多變數能在過程中改變。數種針對飛機、地面和果園施噴之下風沈積模型正在開發中，應該在未來幾年可以取得。當這些模型正確可獲得時，應該以提供單獨飄積研究的骨架來引導飄積研究。某些變數可用這些模型測試而實際的田間試驗可用來證明有疑問的參數變量。

許多不同的 protocol 被用在飄積試驗。收集器、追蹤器、收集位置、施用過程，和分析技術變化的十分廣。隨歐盟的開發，噴灑器具的標準測試程序，包含量測作物上的沈積和飄積，正在開發中。似乎這將領導世界上包含美國的其他地方標準化。一旦量測飄積的標準方法適用於許多地方，大量的數據應可獲得來定義因更多次要因子如地形、山谷風之影響等之不同。

在回顧許多有關於字不同形式的施噴器具量測飄積的研究後，吾們可以總結其結果如下：地面噴桿施噴機具：總飄積約為施噴量之 5%，在下風的前 10 公尺有一半量落在地面；施噴 90 公尺左右約有 1/10000 地面沉積落到外面。在下風 10 公尺處滯空式流量在 2 公尺高之位置約為同距離的地面沉積量高 2 到 10 倍。要減少施噴百分比在”可飄積”大小的範圍(約小於 100μm 直徑)可改變噴嘴型式，降低噴嘴壓力，使用輔助物等減少飄積；例如，使用水加入加濃物通常可以在前 10 公尺減少地面沉積至 0.5 到 0.75 的沉積量。降低噴桿的高度亦可減少飄積。

氣象因子：溫度和相對溼度影響霧粒的蒸散速率，這些因子在前 10 公尺可能對沉積不會有太大的影響，但是可能會影響霧粒長範圍之分離。風速是一個重要因子；增加風速可能會增加行寬位移及被帶離行寬的施噴量。無論如何，增加風速可能會在下風的位移行寬內立即降低地面沉積。

由施噴的果樹和葡萄園下風地面沉積隨下風距離增加而迅速減少。超過施噴面積邊緣 30 公尺，地面沉積量通常少於施噴量的 0.3%。滯空式沉積隨下風距離增加而減之量少於地面沉積。自果園邊算超過 30 公尺，滯空式沉積通常少於施噴量的 3 %， 同時空中飄積施噴濃度由地面計至約 10 公尺左右是接近均勻。

空中噴藥導致在 10 公尺內約多 5 到 10 倍的地面沉積，同時滯空式施噴流量較地面噴桿施噴大 5 到 10 倍。鼓風式噴藥機一般而言比飛機施噴有較低的地面沉積和滯空式施噴流量。然而在某特定狀況下，如使用低容積與小霧粒，鼓風式噴藥機具可能比空中施噴多飄積量。此篇回顧包含了施噴超出預定寬度外之動作，但不含考慮如何改變噴藥系統以減少飄積，將改變噴嘴組合、植物覆蓋或施噴的目的、生物的功效等。

METHODS OF DRIFT CONTROL

H.E. Ozkan, R.D. Fox, R.C. Derksen, R.D. Brazee[1]

ABSTRACT

Factors effecting the amount of spray drift include: spray droplet size, droplet release height, wind velocity and direction, air temperature and relative humidity, atmospheric stability, and droplet release velocity. These factors are important to several application methods, i.e., aerial, ground boom, and air-blast tree sprayers. Downwind deposits from spray drift can be minimized by optimizing these factors, i.e., spraying a low percentage of driftable droplets (< 150 μm), releasing droplets close to the target, spraying in cool humid conditions, with low wind velocities. Of course, if integrated pest management techniques are applied, wherein spray is applied only when required, then less spray will be applied and drift will be automatically reduced. Other special techniques can be used for each application methods. This review contains some examples of drift measurements using boom and air-blast sprayers, and lists management practices for minimizing drift for each application method. For ground boom sprayers, drift management practices include: air-assisted sprayers, electro-static sprayers, using nozzles designed to produce larger droplets and to produce fewer small droplets, such as air-induction, or dual orifice nozzles, applying larger volumes of water, which will require larger nozzles, and using mechanical shields to reduce the effect of wind on the spray cloud. For orchard spraying, one drift reduction technique is to use special spray treatments on the last few downwind rows. These treatments may include spraying only into the wind, using special nozzles that produce large droplets, timing spray applications so the wind direction is favorable, or even using pest control agents with low toxicity for this part of the orchard. Other drift reduction techniques include: use special equipment, such as tunnel sprayers; using hedgerows to filter out spray droplets from the air; and matching the sprayer air jet velocity and volume to the tree being sprayed, and applying the proper spray volume for the tree canopy being sprayed.

INTRODUCTION

Spray drift is defined as the movement of spray out of the intended sprayed area. Some ways pesticides move include: 1) spray droplets can be transported out of the sprayed area by the wind, 2) volatilization of pesticide formulation after application, 3) movement of small specks of pesticide that is lifted from leaf surfaces or the ground after it dries, 4) pesticide deposited on the ground may be transported

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by water or soil particles into the water table or into drainage ditches, streams or ponds. In this study we will only consider the movement of spray droplets during or immediately after spraying as drift. Other means of pesticide movement are difficult to control by changing the spraying equipment or operating procedures.

Factors effecting the amount of drift include: spray droplet size, small droplets are more easily transported by wind currents; droplet release height, droplets released at greater heights take longer to reach the ground and can be carried further; wind velocity and direction, higher velocity means the droplets will be transported greater distances during the time they take to fall to the ground; air temperature and relative humidity (water vapor deficit) affect the evaporation rate of droplets and thus the drift potential; atmospheric stability may affect the vertical transport of the spray cloud, and, in this way, the droplet dispersion pattern; and droplet release velocity may affect droplet travel time from release to impaction on the ground.

AMOUNT OF SPRAY DRIFT

The amount of spray drift is related to the field size and shape, and type of spray application. Many studies have collected spray across the sprayed swath or on the target tree canopy. We will report a sample of these results, as drift is related to the amount of spray that is not deposited in the intended swath.

Ground sprayers

Bode et al. (1976) reported on a series of experiments using the dual-tracer technique to compare two boom sprayer systems with each pass. They measured climatic factors and used a range of concentrations of Nalco-Trol, nozzle type, pressure, and height, and liquid application rates. They measured ground deposits in the swath and from 0.5 to 312 m downwind. A portion of their results are shown in Table 1. Adding Nalco-Trol to the spray mix consistently reduced total spray loss and reduced downwind deposits even more. Increasing the concentration of Nalco-Trol in the mix decreased spray drift deposits for the concentrations used in this study. Low pressure nozzles (8002LP) reduced drift in 4 of 5 trials; TK-2 flooding, flat-fan nozzles decreased drift in 3 of 4 trials but usually not as much as LP nozzles. The Raindrop nozzle decreased downwind spray recovery in 5 of 5 trials compared to an 8002 nozzle, overall drift from the raindrop nozzle was similar to drift from the low pressure nozzle. Wind and other climatic factors varied among experiments so comparisons not paired on the same spray trial must be made with caution.

Goering and Butler (1975) measured downwind ground deposits for a boom sprayer equipped with two booms so that paired trials could be made. They concluded that Nalco-Trol reduced drift deposits by 49 to 75 percent; lowering nozzle height and nozzle pressure decreased drift. Increased air turbulence (Richardson No.) produced greater spray loss but less downwind deposits and increased horizontal wind speed produced greater spray loss but produced either greater or smaller drift deposits, depending on other meteorological factors.

Table 1. Drift from boom sprayer, ground deposits. Adapted from Bode et al. (1976)					
Nozzle type, pressure, kPa	Tank mix	Total spray recovered, %	Spray drift, % (of recovered)	Drift beyond 2.5 m, % (of recovered)	Drift beyond 2.5 m, if 400 m sprayed, %
Flat-fan 8002, 170 to 345	Water	73 to 87	5.2 to 20.8	1.1 to 3.7	2.2 to 7.1
8002, 170 to 345	Water + Nalco-Trol (0.03 to 0.125%)	68 to 97	1.4 to 12.3	0 to 1.8	0 to 2.26
8002LP,100	Water	77 to 101	0.3 to 9.1	0.03 to 1.2	0.03 to 2.0
Flooding TK-2, 69	Water	59 to 107	1.8 to 6.5	0.1 to 0.4	0.1 to 0.5
Raindrop, 276	Water	91 to 103	2.7 to 6.7	0.2 to 0.7	0.2 to 1.1

Table 2 presents results of an exercise designed (Maybank et al., 1978) to calculate the total airborne spray that might leave the downwind edge from spraying a section (260 ha) of land. They calculated these amounts by overlapping measured airborne spray downwind for one spray swath. If all airborne spray left the field within 4 m of the ground, then total airborne drift through this region would be from 95 to 580 mg/m^2 (depending on application type and conditions) if 55 mg/m^2 were applied. Of course, airborne spray will likely be transported to much greater heights than 4 m by the time it travels 1.7 km, but this exercise does point out how much airborne spray may leave the edge of a sprayed field.

Table 2. Estimates of mass flux from spraying of a section of land (1.7 by 1.7 km) at a rate of 55 mg/m^2. Adapted from Maybank et al. (1978).						
Relative contribution to drift from	Downwind field edge			500 m further downwind		
	Aircraft lapse	Ground rig lapse	Ground rig inversion	Aircraft lapse	Ground rig lapse	Ground rig inversion
first swath	1.0	1.0	1.0	0.1	0.2	0.3
2nd –5th swaths	1.3	2.0	2.4	0.3	0.7	1.1
6th-10th swaths	0.9	1.7	2.2	0.4	0.9	1.3

11th-30th swaths	2.1	5.0	6.8	2.3	3.4	5.1
31st-120th swaths	4.4	14.7	25.4	3.54	12.5	22.3
Total	9.7	24.4	37.8	5.5	17.7	30.1
If initial drift is:	30%	3%	3%			
Ave initial drift density(1 swath) to 4 m height (mg/m^2)	60	5.4	5.4			
Total drift (all swaths) ave to 4 m height (mg/m^2)	580	130	200	330	95	160
Ave to 9 m height (mg/m^2)	230	50	80	130	35	65

Air-blast sprayers

Spray accountability

A question we may ask ourselves is: can we account for all of the spray applied to orchards? What portion is deposited on the canopy, on the ground and remains airborne beyond a certain distance downwind? Most of the results presented here were for full-foliage trees, so we will consider the case of air-blast spraying of trees with foliage. We calculated percentages on the basis of tracer applied per unit area. Thus the results are worst case values. If more than the outside row were sprayed, some of the downwind spray would deposit within the sprayed area and a lower percentage of the total spray would be deposited downwind from the orchard. Measured deposit on foliage by Herrington et al. (1991) were about 40% for air-blast sprayers. Siegfried and Holliger (1996) stated that about 40-50% of spray was deposited on the leaves and fruit, about 20% on the ground and about 20% lost as drift. The total spray deposited on the ground from the orchard edge to 30 m downwind was calculated and shown in Fig. 1 for several of studies by Fox et al. (1990, 1993a,b, 1994) and Ganzelmeier (1995). The mean total ground deposit was about 10 to 15% of applied spray. Airborne spray deposits

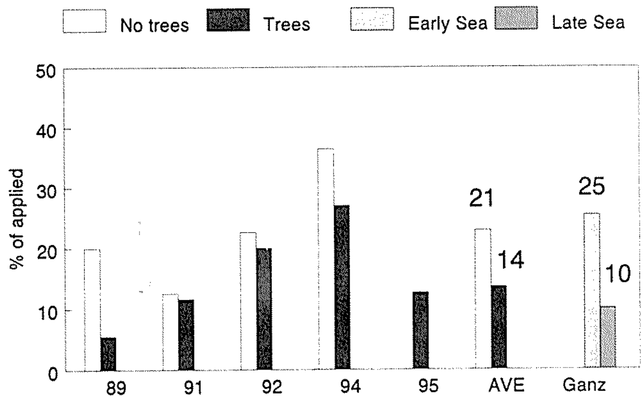

Figure 1. Total ground deposits from the orchard edge to 30 m.

at 30 m downwind were also totaled from the ground surface to 10 m; because data were limited, and several assumptions were made, these results are considered to be subject to large errors, but airborne spray from 0 to 10 m was about 12% of sprayed. Therefore the total of deposits on foliage, on the ground and airborne is 70%. Thus it appears that about 30% or applied spray is still unaccounted for. With no justification, this missing spray is likely to be distributed as 15% additional on foliage, 5% additional to ground deposits and 10% to airborne spray. Thus the spray partition is likely to be about 55% on the foliage, 20% on the ground and 25% airborne as small droplets.

Pergher and Gubiani (1995) measured the effect of spray application rate and vineyard foliage density on spray distribution. Increasing spray application rate and air jet volume produced greater ground deposits and less foliage deposits. Ground deposits were of about 35% of applied spray for 310/390 L/ha application rate and 41 to 49% for 650/730 L/ha application rate. Off-target drift ranged from 6.5 to 10.5% for low air output (7 m^3/s) and from 7.8 to 19.8% for high air volume (8.5 m^3/s). Greatest deposition on foliage (about 55% of amount sprayed) was for low spray volume and low jet air flow rate. Many studies have measured spray deposit patterns from air-blast sprayers in orchard canopies. These studies include: Hall et al. (1975), Whitney and Salyani (1991), Salyani and Whitney (1991), Salyani (1994), Derksen and Gray (1995), Hoffman and Salyani (1996), and Travis et al. (1997) and many others.

Aerial spraying

In most cases, experiments have shown that spraying with either fixed-wing or rotary-winged aircraft produces more drift than other application methods. This is caused by the high travel speed (180-260 km/h for fixed wing), the wing-tip vortices that tend to transport droplets above the wing, and the release height. To reduce drift, spray droplets for many agricultural aerial applications tend to be large, i.e., about 500 μm. In some forestry spraying, very small droplets are used and the wind is used to help increase the effective swath width. The SDTF and the USEPA have adapted a U.S. Forest Service model for use in predicting downwind drift deposits from a variety of aircraft types and spraying conditions.

DRIFT CONTROL METHODS

Education

Several methods can be used to reduce off-site drift. The key to any drift mitigation is the sprayer operator. The operator must configure the sprayer correctly for the crop and must be aware of sensitive sites near the vineyard, nursery, or orchard; must be aware of wind and weather conditions and how they change; and must operate the sprayer in accordance with good drift management principles. In short, sprayer operators must be properly trained and motivated or almost any sprayer system is likely to produce excessive drift.

Calibration

The operator must know how to calculate the amount of chemicals to mix and how to determine tractor travel speed so that he knows how much spray material is being applied.

Drop size control

Drop size is a critical factor in reducing drift. The largest droplet size that will produce the desired biological effect should be chosen to minimize drift. This usually means operating the sprayer at a low system pressure that increases droplet size and/or selecting larger orifice nozzles, or nozzles that produce larger droplet sizes.

Some spray adjuvants are being sold that increase the volume median diameter of spray produced by many nozzles. These 'drift retardants' are normally some type of long chain polymer or gum that increases the viscosity of the spray mixture. Normal application rate for these materials is about 0.0625%. Some studies have found that some of these polymers tend to be sheared by passing through a sprayer pump, as would occur in normal bypass, hydraulic mixing in common agricultural sprayers (Zhu et al., 1997). This means that the drift retardant would lose its ability to increase droplet size – its ability to reduce drift – as the spray tank became empty. Gums are not sheared as easily as the long chain polymers, and some types of polymers (poly-ethylene oxide) are sheared in fewer passes through a pump than other types of polymers (polyacrylamides). In most cases, it is more effective to select nozzles to produce the desired drop size rather than attempt to increase droplet size with an adjuvant.

Nozzles

Dual orifice nozzles reduce the pressure on the flow control orifice; this greatly increases the volume median diameter ($D_{V0.5}$) of spray droplets. However most of these nozzles still produce large numbers of small (less than 150 μm), drift-prone droplets. Air induction (AI) nozzles have been introduced in the last few years. These nozzles provide an air inlet port in a mixing chamber between two orifices. Thus, air becomes entrained into the spray mixture, and most of the small droplets are eliminated. Many studies are now being conducted to evaluate the effectiveness of these nozzles, both to reduce drift and to provide good biological control.

Boom Height

Drift is reduced when droplets are released as close to the target as possible. However the boom must be high enough to provide a good spray pattern from the nozzles. Thus, 80° nozzles must be about 0.5 m above spray targets, while 110° nozzles can be somewhat lower. Boom height is also limited by the possibility of physical damage due to impacting the ground while traveling over rough ground. This danger is increased when travel speeds are increased, when the ground is uneven, and when a boom suspension system is poorly designed. In the U.S. commercial operators with large 'floater' spray rigs often travel 20 to 30 km/h, and so they use large orifice nozzles on booms nearly 2 m above the ground. Any small droplets produced by these nozzles are not likely to reach the ground until carried there by the wind.

Air-assisted

Several commercial sprayers equipped with air jets along the spray booms are now being sold. Hydraulic nozzles direct the spray droplets into the air jets. These air jets should offer some protection against drift, and should improve the penetration

of spray into target canopies. However the angle and air velocity of the jet must be adjusted to provide optimum results. Factors that must be considered in the jet operation include the wind velocity and direction, travel speed and direction with respect to the wind direction, and ground cover (plant canopy) being sprayed.

Electrostatic

Some commercial sprayers now feature electrostatic charging of spray droplets. These sprayers are more expensive to purchase, however may be valuable for treating some high value crops. Some studies have shown improved deposition with electrostatic spray, however other studies have not found significant improvement. To obtain a strong electrostatic force between spray droplets and plant surfaces, the charge-to-mass ratio must be large. However to achieve a large charge-to-mass ratio, droplets must be small, which also makes them more susceptible to drift. The electrostatic force is not effective until droplets move close to leaf surfaces, so if a wind is present, small droplets may be carried away from target plants before droplets are close enough for electrostatic forces to become effective.

Shields

Mechanical shields have been adapted to commercial sprayers for several years (Rogers and Ford, 1985) . These units allow farmers to spray when wind speeds would be too great to permit spraying with conventional boom sprayers. However totally enclosed 'shrouded' sprayers have the disadvantage that the operator can not see if the spray nozzles operating properly, i.e., if a nozzle is plugged. Most studies have shown that these shields do reduce drift by about 90% (Wolf et al., 1993). Other shields made of mesh fabric have also been sold. In wind tunnel studies, Ozkan et al. (1997) have shown that mesh shields are less effective than more conventional solid shields.

Wind

In the U.S., some states have regulations that prohibit spray application when wind speed are above a fixed velocity, such as 20 km/h. Sprayer operators must know where sensitive areas are located with respect to the sprayed field, and must monitor wind speed and direction during spray application. The operator must be responsible for halting spray application if wind speed or direction creates a threat of drift to a sensitive area.

Inversions

Atmospheric stability affects the vertical mixing of the spray cloud into the air and can affect the distance spray droplets drift. Often very stable conditions (vertical mixing suppressed) is associated with low wind velocities, so it is difficult to separate the effect of wind speed from stability. Most research studies have measured increased ground deposit at downwind distances less than 10 m when stability increased. With calm winds and very stable conditions, many experts advice against spraying. Under these conditions, small droplets can "hang" in the air and then be carried by slow moving air currents several 100 m and the entire cloud deposited in high concentrations. This cloud may move in any direction so any

sensitive area close to the sprayed field may be affected. Watt (1979) gives some anecdotal stories of aircraft spraying under these conditions.

Biological agents – less toxic pesticides

While the pesticide used does not necessarily affect the amount of drift, in some cases growers have changed pesticides when spraying portions of crops where the danger of contaminating a sensitive area was great. In these cases, a less toxic, or biological control agent would be used, so even if drift occurred, the danger to the sensitive area (such as a school, swimming pool, or playground) would be low.

DRIFT MITIGATION TECHNIQUES – GROUND BOOM SPRAYERS

1. Use nozzles that produce large droplets whenever possible, if biological effectiveness can be maintained.
2. Keep the boom close to the spray target.
3. Use nozzles with narrow spray-fan angles.
4. Use greater spray volume and use nozzles with larger orifices.
5. Use lower system pressure and check pressure gauge accuracy.
6. Use drift retardants if droplet size can not be controlled with nozzle selection.
7. Follow label recommendations to avoid drift with highly volatile pesticides.
8. Avoid spraying on extremely hot, dry days, especially if sensitive vegetation is nearby.
9. Do not spray when conditions are favorable for an atmospheric inversion.
10. Do not spray when wind speeds are greater than 15 km/h.
11. Avoid spraying near sensitive areas located downwind. Leave a buffer strip 20 to 30 m wide and spray this strip later when the wind shifts.
12. Be sure to keep good records and evaluate spray results.
13. New label requirements may use a drift model to determine the required buffer width. Travel slower (and lower boom height) and use nozzles which produce large droplets near sensitive areas. This will reduce the required buffer zone width, then, as distance from the sensitive area increases, nozzles can be changed to produce smaller droplets, if desired, and boom height raised so travel speed can be increased.
14. Select the time when drift is likely to be low for spraying the parts of the field near sensitive areas.
15. In the future, label requirements may specify nozzles that produce a certain droplet size spectrum, such as fine, medium, coarse, very coarse, etc.

DRIFT MITIGATION TECHNIQUES – ORCHARD AND VINEYARD SPRAYERS

Many of the same principles for reducing drift for boom sprayers apply to orchard spraying as well. With airblast sprayers, we have to remember that the

droplet release height is where the air jet no longer controls the droplet trajectory and the wind begins to direct droplet paths. In some cases, this may be several meters above the tree canopy. Some of the practices for reducing drift are: 1) keep the spray as close to the ground as possible; 2) minimize the small droplet fraction; 3) match the sprayer air jet and nozzle system to the trees being sprayed; 4) use special techniques near sensitive areas. Most of the techniques discussed below use one or more of the techniques mentioned above.

Overhead application

Carpenter et al. (1985) tested a micro-irrigation system over the tree row as a possible automatically controlled pesticide application system. They were able to design a system that worked fairly well, but the system required a large amount of water and wind currents prevented uniform coverage under some conditions.

Tree sensing

McConnell et al. (1983) proposed a spray system that would use ultrasonic sensors to evaluate tree volume for use in control of spray volume. Sutton and Unrath (1984) discussed using tree volume as a basis for the volume of spray to be applied. Giles et al. (1987) used a tree sensing system and a spray control system to develop an air-blast orchard sprayer that sprayed only when canopy was detected. The sprayer used sensors at three elevations to detect foliage; each sensor controlled spray from the nozzles directed at the associated elevation in the tree. They tested the sprayer in a peach and an apple orchard. They found that tree-sensing/spray control saved 28 to 35% of spray material in the peach orchard and 36 to 52% of spray in the apple orchard, compared to the same sprayer without controlled spraying. Spray cards were used to evaluate spray deposit at locations within the trees. Targets at some locations, near the leading edge of foliage near tree gaps and in the upper regions of the tree, received less spray when the tree-sensing system was used. Commercial units that use this type of system have been available for several years. In Spain, Rosell et al. (1996) developed an electronic selective spraying system which sensed tree volume as the sprayer moved down the row and adjusted sprayed volume to match measured tree volume. If no tree canopy was detected, then no spray was applied. Spray trials in pear trees found that about 50% less spray was applied with the selective sprayer as compared to the same sprayer with the sensing controller system not used.

Tunnel sprayers

Home built tunnel (over-the-row) sprayers have been used in crops such as grapes and small fruit for some time. With increased concern for drift reduction, several researchers throughout the world have recently designed and tested experimental tunnel sprayers. It is likely that this technology will be adopted for tree fruit in Europe more quickly than in the U.S. because recent plantings of apple orchards in Europe tend to be more uniform, dwarf varieties. Tunnel sprayers may not only reduce drift and improve deposit, but allow the possibility of collecting spray that misses foliage for reuse. A disadvantage of the tunnel sprayer is the size of trees that can be treated and problems associated with driving such a large machine through the orchard. Morgan (1983) reported that experimental over-the-

row devices had been used in spray trials on fruit crops in Great Britain several years earlier. Tennes et al. (1976) developed an over-the-row harvester that could straddle trees 2.6 m wide and 3.7 m high. Reichard et al. (1982) developed an inline injection sprayer attachment for this unit. Schmidt (1990) measured ground and airborne spray while using a tunnel sprayer that collected and recycled spray that collected on the tunnel walls. The tunnel sprayer with recycling produced about half the ground deposits as a standard axial fan sprayer.

Van de Werken (1991) described the development of a fully automatic air-assisted tunnel sprayer for use in apple orchards. This self-propelled unit also recycled s99pray deposited on the tunnel walls. This sprayer required a travel path at least 0.4 m wide for travel. It could spray tree-rows up to 2 m wide and 3 m high at travel speeds up to 6.3 km/h. They found that 90% or more of the spray was deposited on trees with this sprayer. Cross and Berrie (1993) compared spray deposits and efficacy of sprays applied to apple trees with a tunnel sprayer and a conventional sprayer. More deposits and better scab control was achieved with the tunnel sprayer applying 100 and 200 L/ha compared to conventional or tunnel sprayers applying 50 L/ha. Peterson and Hogmire (1994) developed and tested a self-propelled sprayer for dwarf fruit trees. The tunnel was 2.4 X 4.7 m, with a vertical clearance of 2.4 m. Three air-delivery systems were used within the tunnel unit: 1) no air; 2) four Proptec® fans; 3) four cross-flow fans. They measured deposit within the tree canopy and drift from these sprayers and from a conventional axial-flow fan sprayer while applying 190 L/ha. Samples were taken from the outer 0.5 m and in the center of the tree canopy, between 0.7 and 1.7 m elevation. The cross-flow fan units deposited more spray in all sections of the trees than the Proptec equipped sprayers. Hydraulic nozzles without fans had good deposits in the upper parts of the trees. Hydraulic and spinning disk nozzles produced similar deposits in all sections of the tree. In a single test, low volume (187 L/ha) produced greater deposits than high volume (935 L/ha). The best tunnel configuration produced greater deposits than the conventional sprayer. The tunnel sprayer had significantly less drift than the conventional sprayer.

Holownicki et al. (1996) compared two tunnel sprayers, one with cross-flow fans and the other with eight directed air-jets with a standard sprayer with 10 directed air-jets. Tree-row size was 2 m wide and 2.5 m high, with a row spacing of 4 m. There was no significant effect of travel speed and spray volume on total deposits. Increased travel speed caused slightly reduced spray deposits for the tunnel cross-flow sprayer. For targets along the vertical centerline-axis of the tree, significantly greater deposits were measured for the standard compared to the tunnel cross-flow sprayer. They measured the ratio of outside to inside canopy deposit. Measured ratios were: directed air-jet tunnel sprayer - 1.5 to 3, cross-flow tunnel sprayer - 7.5 to 14.6, and directed air jet sprayer - 5 to 12.7. Thus the best distribution was for the directed air jet tunnel sprayer. Wilson, et al. (1995) developed an over-the-row dust applicator for fruit trees. The tunnel was 4.3 m in all three directions. Measured deposits varied from 15 to 36 mg/cm^2 on sampled leaves taken from three trees at 0.2 m in from the canopy edge, at 1 and 3 m elevations and at 4 quadrants within the tree.

When spraying dormant trees, Siegfried and Holliger (1996) reported that in small trees, a tunnel sprayer achieved 60% greater deposit on branches, twigs, and scaffold compared to an axial-fan sprayer; however, deposit was not improved in

older fruit trees with wide tree tops. Ground deposits were 20-40% lower and drift was reduced by 70% with tunnel spraying compared to axial-fan spraying. At full foliage, the tunnel sprayer deposited about 20% more sprayed material on leaves than axial-fan sprayers. However, at full foliage, ground deposit with the axial-fan sprayer was reduced to within 5% of the tunnel sprayer (28% to 23%).

Reports of several other studies on tunnel sprayers are contained in the Symposium proceedings cited earlier (A.N.P.P.-B.C.P.C., 1993).

Barriers

Orchard trees have been shown to be good collectors of spray that penetrates target trees. Riley and Wiesner (1990) reported that most ground deposit resulted from spraying the last, downwind row. Downwind ground deposits decreased rapidly as the sprayed row was farther from the downwind edge of the orchard. They developed a regression equation to estimate deposit produced from spraying interior rows, based on row distance from the orchard edge. The SDTF (1998) measured large decreases in deposit away from the sprayed row in the interior of an orchard. Thus a major factor in downwind deposit near the orchard is the spraying of the last few rows. Special treatment of these rows can greatly reduce off-target drift.

Researchers in New Zealand have conducted several studies on the effect of shelter belts on drift from orchard sprayers. Graham (1987) measured ground and airborne spray deposits downwind from a conventional orchard sprayer as it sprayed in the open (no shelter belt), through a natural (live) shelter, and through an artificial shelter. The natural shelter included *Casurina spp* and *Matsudana spp* which were about 7.6 to 10 m high. The artificial shelter was made of medium porosity Sarlon cloth, 6 m high. Measured ground deposits of the fungicide Ronilan, used as the tracer, are shown in Figure 2. Ground deposits appear to be reduced by the presence of shelters; the live shelter had a greater effect than the artificial shelter. They used both air samplers and rotating slides to collect airborne spray. Air samplers collected more spray then either ground or rotation slides on an area basis. The live shelter also produced the greatest reduction in airborne spray collected by both methods, but the artificial shelter also reduced deposits compared to no shelter. They suggested that the "ideal" porosity for a live shelter was such

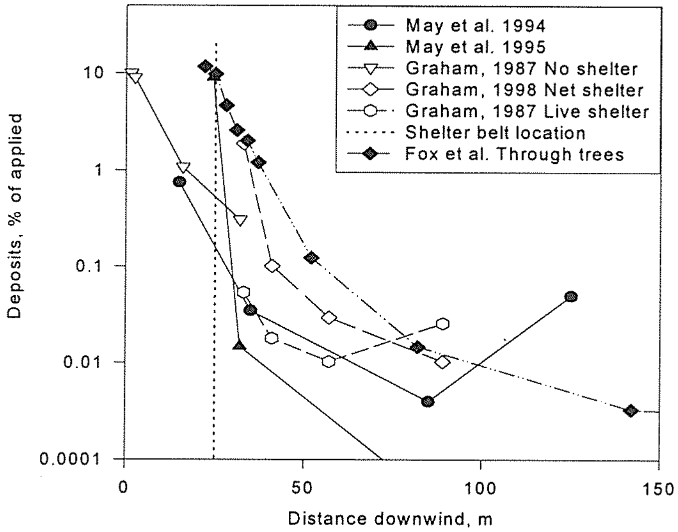

Figure 2. Ground deposits downwind from shelter-belts.

that you could see the sprayer through the trees, but could not see any detail, such as make, driver, etc. Artificial shelters made of woven cloth should have an optical porosity of 40 to 50%.

May et al. (1994) used a conventional orchard sprayer for three trial sprays along a path in a grass field, 25 m upwind of a live shelter which contained poplar trees, 9 m tall and 2.7 to 5.8 m wide. They measured ground and airborne spray deposits at 10 m before and 10, 60, and 100 m beyond the shelter belt. The shelter was trimmed after the second trial so a 2 m tall fence of shade cloth was installed to reduce spray passage. Thus trial 3 had much less deposit that the first two, even though the wind was greater during trial 3. The wind during the first two trials was less than 10 km/h. They concluded that, for the conditions of their study, the shelter belt was not effective in reducing downwind deposits. Mean ground deposits for their trials are plotted in Figure 2. Ground deposits at 128 m were noticeably greater than deposits at 85 m, for all trials. It was not determined if this was a result of air flow patterns over the shelter-belt or not. Graham (1987) also measured an increase in deposits on the last downwind ground sampler (see Figure 2).

In another study, May (1995) measured deposits beyond a large, dense evergreen shelter-belt when a persimmon orchard was sprayed. They used two pesticides as tracers. Ground deposits were below detectable levels at 75 m downwind. However, detectable levels of airborne spray were measured at 75 m downwind. These results are also plotted in Figure 2. Combined ground deposits measured by Fox et al. (1990,1992,1994) downwind from spraying through a single row of semi-dwarf apple trees are shown in Figure 2 for comparison.

Summary of drift mitigation practices for airblast sprayers

Drift mitigation methods can be summarized then as:

1. if there's nothing there, don't spray it;
2. keep the spray as close to the ground as possible;
3. minimize the small droplet fraction; however remember that the purpose of spraying is to control pests. Large droplets may not provide the control desired, without increasing the application rate;
4. match the sprayer air jet (volume and direction) and nozzle system to the trees being sprayed;
5. Be prepared to use special techniques near sensitive areas, especially for the last few downwind rows. These may include: a) use large droplets; b) use techniques to direct spray at targets better, such as a handgun; c) spray the last few rows upwind only; d) wait and spray when the wind shifts; e) use special measures or equipment to create barriers or direct spray at the target (tunnel sprayer, etc.).

In their discussion of reducing pesticide drift, Hall and Fox (1996) report a summary of recommended procedures for reducing off-target movement of pesticides. This list of actions, resulting from a Tree Crops Workshop held in 1993, and provides a good summary of approaches that should reduce drift from orchard spraying. An abstract of this action list is given in Table 3.

Table 3. Mitigation options for Orchard Air-blast Applications*

Action	Rank	Estimated % drift reduction	Comments
Education	1-3	20%	1. Survey current practices 2. Train individuals to critically adjust sprayer for planting geometry match/season and tree size
Modify edge practices	1-3	40-50%	1. Least costly and probably easiest practice to accomplish 2. Spray inwards on outer 4-6 rows 3. Decrease spray volume (psi and/or liquid volume) 4. Automatic or manual shut-off (sprayer) on last 4-6 rows.
Restriction of ai/applications	4	15-20%	1. Restrict by ai and time of day [not 10:00 am to 4:00 pm] 2. Can restrict ai, e.g., safe pesticides only in high risk areas
Sensors	5	20-25%	1. This technology should be accelerated; currently not cost-effective for small growers.
Buffer zones	6	15-20%	1. Effectiveness would depend upon width of buffer, size of tree and/or block, and sprayer
Tower and/or tunnel sprayers	7	10-80%	1. No documentation of % reduction, although visual evidence suggests an increased target placement efficiency; hence a reduced off-target movement. 2. Tunnels useful only for 2.4 m trees/vines [e.g. less than 5% of apple acreage in the USA and no other tree crops]
Narrow droplet spectrum	8	10-15%	1. Possible with "dialable sprayers". Need to change nozzles "on the go".
Wind breaks	9	20-40%	1. Not for pecans or other high trees. 2. Practicality of strategy; will it create other problem?
Overhead or chemigation	10	20%+	1. Use of large drops would reduce off-target movement 2. Limited to certain sites/crops, but has irrigation potential as well.

* Adapted from Hall and Fox (1996)

Drift mitigation for aerial application

There are only a few options available for reducing drift when spraying with aircraft. The first step is an operator who is carefully trained so he/she can make good decisions on when to spray and when to stop spraying. The operator must use a spray offset carefully. That is, he must calculate how far the wind will carry the main spray swath and plan his spray paths to allow for this spray adjustment. The use of global positioning instruments in aircraft should assist the pilots in making sure they are spraying the correct field and in selecting the proper spray paths. New computer software may soon be available to select optimum spray paths in real time, based in local wind and spray conditions. The largest droplet size that will produce the desired biological effect should be chosen.

SUMMARY

Spray drift can be minimized by proper sprayer operation. The key to any drift mitigation is the sprayer operator. The operator must configure the sprayer correctly for the crop and must be aware of sensitive sites near the spray site; must be aware of wind and weather conditions and how they change; and must operate the sprayer in accordance with good drift management principles. Spray practices that reduce drift include: spray large droplets, or use nozzles that produce fewer small droplets, but make sure the desired biological effect is attained; adjust boom height as low as possible, while maintaining a uniform spray pattern across the swath; apply special practices near any sensitive area; use shields to reduce wind effects; spray only when the wind velocity is less than 15 km/h; and wind direction does not threaten sensitive areas such as houses, schools, streams, or other crops that may be damaged or contaminated by the spray material being applied.

Several different methods can be used to reduce off-site drift for airblast sprayers in orchards or vineyards. Some rules of good sprayer operation are: if there's nothing there, don't spray it; spray the last few downwind rows only into the wind; use the largest droplets that will produce the desired biological efficacy; match the sprayer jet and nozzle flow rate to the trees in the orchard.

Other ways to decrease drift include: use tunnel sprayers; use windbreaks downwind of the sprayed area; provide buffer zones between the sprayed area and sensitive neighbors; and use special spraying techniques for parts of the vineyard or orchard where sensitive areas may be subject to drift. These may include spraying some areas only when wind direction is suitable or using biological control or low toxicity pesticides in some areas of the application site.

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施藥飄積控制的方法

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摘 要

影響施藥飄積量的因子包括：施噴霧粒大小、施噴高度、風速、空氣的溫度與濕度、大氣的穩定度、及施噴霧粒的釋放速度，以上這些因子對一些施藥技術而言是非常重要的，如：空中施藥、地面噴桿式施藥、及鼓風式施藥等。而將這些影響因子予以最佳化控制可使在下風處的施藥飄積沉降量降至最低，如：施噴時將可飄移的霧粒（＜１５０μｍ）百分比降低，施噴作業時噴頭儘量靠近施噴對象，施噴作業在低溫、高濕及低風速下進行。在綜合性病蟲害防治作業中，施用農藥只在必要時實施，如此減少農藥的施用自然可降低施藥飄積的發生，另每種施藥方法都可採用一些特別的技術以減少飄積的產生。本論文的內容包括有桿式與鼓風式施藥飄積的量測，及列舉各種施藥方法減少飄積的管理策略，對地面桿式施藥機而言有效的飄積管制措施包括有氣輔式施藥機、靜電式施藥機、使用可使施噴霧粒較大的噴頭，以減少細霧粒的產生，如空氣引入式噴頭、雙孔式噴頭、提高用水量同時使用較大的噴頭，利用機械式遮蔽以降低風對霧粒群的影響。在果園內施藥時可針對在下風處最後幾行果樹以特殊的施噴方式減少飄積的產生，在有風的情況下進行施藥作業時，須使用噴霧霧粒較大的噴頭，掌控施噴作業的時間使風向有利於施噴作業的進行，亦可利用一些特殊的裝備以減少施藥飄積，如：墜道式施藥機、使用灌木籬牆以過濾空氣中的霧粒、作業所使用的空氣氣流速度與流量必須配合施噴果樹的需要、於果樹的樹冠內噴施適當的量等。

引言：

所謂施藥飄積是指施噴的藥霧霧粒超出了預定施噴範圍，農藥施噴後會有多種不同的移動，而本論文主要討論的是霧粒在施噴作業中於空氣內的移動，主要對飄積的影響因子有：施噴霧粒大小、施噴高度、風速、空氣的溫度與濕度、大氣的穩定度、施噴霧粒的擴散型態、及施噴霧粒的釋放速度。

施噴飄積量：

施噴飄積量與田區的大小、形狀及所使用的施藥技術與設備有關。加入

Nalco-Trol 於藥液中可降低施噴的損失，並減少下風處的沉降量，提高 Nalco-Trol 的濃度可減少飄積的沉降量，低壓噴頭可減少飄積，較低的噴頭高度與作業液體壓力均可減少飄積，增加氣流的擾動會提高施噴作業藥劑的損失，但可減少下風處的飄積沉降量，水平風速的提高會增加藥劑的損失，但是否會提高或降低飄積量則需視氣候的條件而定。

鼓風式施藥機：

果園施藥約有５５％的藥劑附著在葉片與果實上，約２０％在地面，及大約２５％的飄散在空氣中。增加空氣流量與施藥量則會降低葉片上的藥劑沉降量而提高地面的沉降量。

空中施藥：

在大部份情況下不論是使用固定翼或螺旋槳飛機進行空中施藥，其施噴的飄積情形均較其它方法為嚴重，飛機的高速運動及機翼所形成的渦旋為造成飄積的主因，為了減少空中施藥飄積的嚴重性，一般農業上常使用大顆粒的霧滴約５００μｍ。在一些森林施藥作業中為增加作業的寬度，可利用風與使用小顆粒的霧粒。

飄積的控制方法：

教育：

有數種方法可用來減少非目標區的飄積，但施藥機的操作人員為影響飄積最主要的關鍵人物，施藥機操作人員必須妥善的規作業，必須清楚的知道靠近作業區的敏感點，必須掌握風速與風向及氣候狀況，同時依據飄積管理控制的法則操作施藥機。

校正：

操作人員必須能妥適的混合藥物，同時掌握適切的作業速度，如此方能確實掌握施噴量。

霧粒大小控制：

霧粒的大小為減少飄積的關鍵因子，大霧粒可減少飄積，因此所操作的施藥機應有較低的作業液壓，使用大孔徑的噴頭，或可產生較大霧粒的噴頭。另使用添加劑亦可減少飄積的形成，一般此類添加劑為長鏈聚合物或凝膠物，可用來增加藥液的粘度。

噴頭：

大部份的噴頭在施噴過程中產生大量具飄積傾向的小霧粒是無法避免的，雙孔式噴頭可降低作業壓力同時提高霧粒的粒徑，氣引式噴頭（ＡＩ）具有一空氣流導入口於兩噴孔間，空氣與施噴藥劑混合如此可抑制小顆粒霧粒的生成。

噴桿高度；

當施藥作業時能儘量地縮短噴頭與目的作物的距離，則可有效地減少飄積，但噴桿仍必須維持其一定的作業高度，以維持其施噴的均勻度。

氣體輔助：

於噴桿上裝置氣流，以此一方面減少飄積的產生，另一方面增加顆粒對目標作物葉冠的穿透力，所使用氣流的方向與速度必須妥善的控制以得到最佳的結果，氣體輔助的利用必須注意氣流的大小與方向，同時注意施藥機運行方向與氣流方向的對應關係。

靜電式噴頭：

靜電式噴頭之價格遠較一般噴頭為高，但其對某些高價作物仍具有一定的吸引力，靜電的效果必須作物與霧粒甚為接近時方為有效，且單位質量的帶電量必須高，另氣流的存在會降低靜電效果。

遮蔽：

機械式施藥遮蔽系統已商品化多年，此裝置使施藥機械能在強風下進行作業，但密閉式的遮蔽系統則有阻斷作業者觀察噴頭狀況的缺點。

風：

在美國有數州禁止施藥機於風速超過２０ｋｍ／ｈ下作業，作業者必須確實了解對所施農藥的敏感點，在作業時應充分掌握風向與風速，絕對避免危害這些敏感點。

氣候穩定性：

大氣的穩定性對霧粒的垂直混合與飄積有很大的影響，完全無風的狀態並不適合進行施藥作業，此時小顆粒霧粒會長期懸浮在空氣中，同時非常微弱的風即可將顆粒吹送相當的距離。

地面桿式施藥機之飄積抑制技術

1. 在不影響施藥作業效果下，儘可能地使用能產生大霧粒噴頭。
2. 噴桿須儘可能地接近施噴標的物。
3. 使用噴角小的扇型噴頭。
4. 使用大噴孔噴頭及增大噴量。
5. 使用低壓系統同時檢查壓力計的正確性。
6. 若無法以選用噴頭方式控制飄積時，利用飄積抑制劑。
7. 對高揮發性藥劑，應依說明書的規定使用。
8. 避免在高溫乾燥的環境進行施藥作業，尤其是有對農藥敏感的作物存在時。
9. 當氣候穩定性差，對飄積有利時應避免施藥。
10. 當風速超過１５ｋｍ／ｈ時，應避免進行施藥作業。
11. 當對農藥敏感地區在下風處時應避免施藥，施藥時應預留２０ｍ至３０ｍ寬之緩衝帶。
12. 應保持完整的施藥作業記錄，並評估施藥效果。
13. 當使用新藥時，應利用飄積模式決定緩衝帶的大小，作業時應降低作業的速度與噴桿作業高度，同時使用大霧粒的噴頭，可縮小緩衝帶，若作業時敏感區較遠時可使用小霧粒噴頭，同時提高噴桿高度與施藥機作業速度。
14. 在農藥敏感區附近進行施藥作業時，應選飄積效應較低的時段進行。
15. 在未來藥劑的說明可能必須述明噴頭所產生霧粒分佈的狀況，如細、中度、粗及非常粗等。

果園與葡萄園施藥機飄積抑制方法

許多桿式施藥機適用之飄積抑制原則亦同樣適用於果園用施藥機，但當使用鼓風式施藥機時風速為控制藥霧粒運動路徑之主要因子，在某些情況下藥霧粒可能受風影響，其高度超過樹冠數公尺高，因此在使用此類施藥機時要減少飄積需注意下列事項：

1. 施藥作業的噴施動作越接近地面越好。
2. 儘可能的減少小霧粒的產生。
3. 施藥系統與氣流的應用必須配合對象果樹的特性。
4. 在接近農藥敏感區時，採取必須特殊的施藥方法。

鼓風式施藥機飄積抑制方法

1. 無必要時請勿進行施藥。
2. 噴施作業儘可能地接近地面。
3. 儘可能地避免小霧粒的產生，但施藥作業的主要目的在進行病蟲害的防

治，若使用大霧粒時不增加施噴率，可能會使病蟲害防治效果不如理想。

4. 對接近敏感區的作物及下風的最後數行作物，必須準備使用特殊的施藥技術：ａ．用大顆粒霧粒。ｂ．使用指向功能較好的施藥設備，如噴槍型噴藥裝置。ｃ．最後數行作物必須在逆風狀況下進行作業。ｄ．當風向轉變時等待確定後再作業。ｅ．用特別的技術或設備形成飄積阻絕器，如墜道式施藥機。

空中施藥飄積的抑制

利用飛行器如飛機進行空中施藥，可用來有效減少飄積的方法並不多，首先作業人員必須有完整而優良的訓練，必須具有判定適合與不適合施藥時機的能力，他必須能判定施藥後風對藥霧粒的影響，如施噴寬度與距離，同時規劃其施噴作業路徑。可利用全球定位系統，協助作業人員確定施噴作業區，未來新的電腦專家系統將能以地區性的氣象資料建立最佳化的即時施藥作業規劃。

結　論

適宜的操控施藥機械可將飄積減至最低，而施藥作業操控人員為有效減少飄積的主要關建因子，施藥作業操控人員必須能依據施藥作業的實際需求，有效的規劃施藥設備，如作業對象，氣候條件如溫濕度、風速風向的大小及轉變，農藥敏感區的存在與狀況。可有效減少施藥飄積的策略有：採大霧粒、使用生成細小霧粒較少的噴頭、確定達到防治效果、在能維持施藥作業均勻度的條件下噴桿高度越低越好、注意對農藥敏感區的保護、可採用遮敝的技術減少飄積的產生、當風速超過１５ｋｍ／ｈ時應避免進行施藥作業，須注意風向不致危害到農藥敏感區：如住家、學校、河流或其它對所噴施藥物有不利反應及敏感的作物等。

針對果園與葡萄園進行空中施藥，有一些方法可用來降低空中施藥的非目標區的飄積狀況，進行空中施藥時，作業操作人員須注意下列作業法則：施噴對象不存在時且勿進行作業，對下風的數行作物進行施藥作業時須於上風處施噴，在能維持所要求的病蟲害防治效果的原則下，儘可能的使用大霧粒，果園施藥必須依對象果樹的特性使用設備及決定其作業條件，如：藥壓，藥流量等。

其它減少飄積的方法包括：使用墜道式施藥設備，農藥噴施作業區下風處可使用防風裝置，施藥作業區與農藥敏感區應供給合適的緩衝帶，當敏感區可能因飄積而受影響時應採取必要的保護措施或特殊的病蟲防治措施，如：只在風向不會對敏感區產生不利影響時才進行作業，使用生物防治技術，或使用一些低毒性的藥劑。

RECOMMENDATIONS FOR IMPROVING PESTICIDE APPLICATOR TRAINING PROGRAMS IN TAIWAN

H. Erdal Ozkan **Robert D. Fox**[1]

ABSTRACT

This paper contains recommendations for improving pesticide applicator training programs in Taiwan based on licensing and training procedures in the U.S.A. and some Western European countries. Also included in this paper is information about a new European Community initiative on mandatory inspection and certification of pesticide application equipment.

In the U.S. restricted use pesticides can only be used by a certified applicator or a person under direct supervision of a certified applicator. Certified applicators must pass written exams demonstrating their knowledge about pesticide use and have met other licensing requirements. The process of license renewal is different in the U.S. and in Western European countries. In most U.S. states, renewal of a license is required every three years. Some European countries do not require recertification, others have recently adopted the concept of recertification and continuing education that comes with the recertification process.

One important difference between the procedures for licensing applicators in the U.S. and in some European nations is in testing the knowledge level of an applicator prior to issuing a license. Most European candidates for a license must pass a one-on-one oral examination and hands-on problem solving session in addition to written tests. To improve the quality of pesticide applicator training programs in Taiwan, the European and U.S. procedures for applicator education and inspection of application equipment should be carefully reviewed. The procedures found suitable for conditions in Taiwan should be revised if necessary, and adopted.

INTRODUCTION

About a third of all pesticides produced worldwide are sold in the U.S. Pesticide industry sales reached $8 billion in 1992 (NACA, 1993). Growing concerns about pesticide contamination of ground and surface water and increasing chemical costs make accurate application of pesticides even more important than in the past. The effects of pesticides are greatly influenced by the method and timing of application, and the operation and accuracy of the equipment used. Applying too little pesticide causes ineffective pest control which may require the added expense of respraying. Applying too much pesticide adds to the cost, may damage the crop, and may lead to environmental pollution. Labels on pesticide containers indicate the proper application rates. However, these rates can be achieved only if the application

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equipment is suitable for the job, calibrated frequently, and operated properly.

Regulatory guidelines in the U.S. indicate that the application should be within 5% of the recommended label rate. Although it is questionable whether an application accuracy with an error margin of 5% can be achieved in "real world" situations, improvements in application accuracy are needed and can be achieved with proper selection, calibration, and operation of application equipment. To obtain such high accuracy levels in application of pesticides requires well-educated and qualified persons applying and handling chemicals.

Although there may be differences in the format for educational programs conducted in the U.S. and in most Western European Countries, all applicators are educated on how to operate and calibrate application equipment properly, and apply pesticides in most effective manner. While some countries do not require a license to apply pesticides, other countries, including the U.S., require a license for applying certain classes of pesticide. The requirements to obtain a license varies from state to state in the U.S., and from country to country around the world.

Very recently, some countries in Western Europe have gone one step further and adopted procedures to certify application equipment. A thorough inspection is conducted as part of the certification process. Sprayers which fail this inspection cannot be used for applying pesticides. Rules of equipment inspection vary from country to country. Some European countries have objected to such regulations.

OBJECTIVES

To conduct new educational programs and improve existing programs for pesticide applicators in Taiwan, procedures followed by other nations around the world should be carefully evaluated. The objectives of this paper are:

1) To highlight the similarities and contrasts among pesticide education and licensing programs in the U.S. and in some Western European nations.
2) To provide information about the new European Community initiative on inspection and certification of pesticide application equipment.
3) To offer some recommendations on improving quality of educational programs currently offered to pesticide applicators in Taiwan.

PROCEDURE

To obtain information on pesticide applicator education and application equipment inspection programs in Europe, a questionnaire was sent to knowledgeable persons in the following countries: Belgium, the Czech Republic, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, and the United Kingdom. The participants of this survey were selected because they are directly involved in pesticide applicator education programs, or are at least qualified to answer the survey questions. To clarify answers given to some of the questions, participants were contacted again, either face-to-face or by telephone, Fax or Internet.

A summary of U.S. and European programs for training pesticide applicators and inspecting application equipment is presented below. Detailed information about these programs in the U.S., and responses to individual questions by survey participants from Europe are given in the paper by Ozkan (1996). Specific responses to a small number of key questions are presented in this paper.

SUMMARY OF KEY FINDINGS

a) *Pesticide Applicator Education in the US and in Western Europe*

The procedure for teaching topics related to application equipment varies from state to state in the U.S., and from country to country around the world. In the U.S., every state training program must meet the minimum established in Federal Insecticide Fungicide Recovery Act (FIFRA) requirements, but many states have their own pesticide laws that are more stringent than the federal law.

In the U.S., some pesticides pose special risks to the public health and environment and therefore are classified "restricted use". All other pesticides are classified as "general use". Restricted use pesticides can only be used by a certified applicator or a person under direct supervision of a certified applicator. Certified applicators must pass written exams demonstrating their knowledge about pesticide use and have met other licensing requirements. These training sessions include core subject matter (safety, environment, regulations, pesticide waste management, equipment calibration etc.) and topics related to specific crops and categories of certification (agronomic crops, horticultural and ornamental crops, aquatic pest control, home pest control). The applicators must attend a minimum 5 hours of educational presentations which should include a minimum of 1 hour of core material, half hour of training on a specific category for which the applicator will be certified.

Proper operation and calibration of pesticide application equipment should be an important part of the total knowledge which all applicators are expected to possess in order to apply pesticides accurately. Although generally the pesticide applicator education programs in the U.S. are the envy of many nations around the world, the part of the program associated with selection, operation and calibration of application equipment receives inadequate attention.

While some states address the topic adequately, most others allocate only 30 minutes to cover application equipment. This training process has generally been ineffective. In many cases, the large size of the audience attending these lecture-oriented teaching activities has not allowed audience participation and interaction with the instructor. In some cases, the subject matter is covered by using slide sets and videotapes with no instructor available to answer questions. The training process has not motivated applicators to calibrate their sprayers.

The written test which the applicators take before obtaining their certificates do not serve as an indicator of the applicator's knowledge in proper operation, maintenance and calibration of application equipment. For example, the Ohio exam for commercial applicators contains 80 questions from the core material, and 25 to 35 questions from a specific category chosen by the applicant. Out of the approximately 110 questions, no more than 10 are directly or indirectly associated with application equipment. Most of these questions, such as mixing chemicals, drift, nozzle selection, properly cleaning a nozzle, reasons for calibration, proper cleaning of a sprayer etc., can be answered by simply using common sense. Since a score of 65% is a passing grade, someone can miss all of the equipment related questions and still become a certified pesticide applicator. This situation is not specific to Ohio only. Delivery of educational programs for training pesticide applicators and the content of exams given to applicators do not change much from state to state.

On the other hand, some European countries require an examination that includes a direct, one-on-one testing with spray equipment before a certified pesticide applicator rating is issued. Prior to this hands-on type exam, the applicator is required to go through a training school which teaches the basic principles of sprayer operation and calibration, and proper handling of pesticides. These schools typically last one to four days depending on the experience of the applicator.

Another concern with U.S. applicator licensing is that only the supervisor is required to hold a valid license. Under his/her supervision, personnel who are not licensed may handle the pesticides and operate the spray equipment. The assumption is that the supervisor will provide adequate training to his/her employees before spraying begins. If supervision is close enough, this policy is adequate and can be practiced successfully. Unfortunately, there is no way of knowing whether the supervisor adequately trains the workers. In many European countries, <u>everyone</u> who is actively engaged in applying pesticides has to obtain a valid applicator license.

The process of license renewal is different in the U.S. and in Western European countries. In most U.S. states, renewal of a license is required every three years. The applicant must either take the written test and pass, or attend educational programs for a minimum of 5 hours. During these structured educational programs the applicator is provided with the latest information on various aspects of pest control. Until recently, recertification of an operator was not necessary in Europe. Once a license was obtained, it was valid indefinitely. Although some European countries still do not require recertification, others have adopted the concept of recertification and continuing education that comes with the recertification process.

b) *<u>Inspection and Certification of Application Equipment</u>*

All countries included in this survey have been conducting voluntary equipment inspection programs for several decades. The low level of participation by pesticide applicators and increasing public concerns about the misuse of pesticides have forced regulators in some countries to implement much stricter rules governing the condition of application equipment. Germany and Belgium have made equipment inspection mandatory since 1993 and 1995, respectively. If a sprayer passes the mandatory inspection, a decal, representing the seal of approval by the regulating agency is placed on the sprayer. These inspections typically include the following: general condition of the sprayer (fittings, hoses, leakage, boom stability, pumps, nozzles etc.), stability of pressure at the nozzle, condition of the pressure gage, pressure variations among boom sections, change in pressure at the nozzle when any one section of the boom is shut off, flow rates of all nozzles, and accuracy of sprayer monitors and control units.

In the first month of the mandatory inspection program in Belgium, 1556 sprayers were inspected. About 87% of these sprayers passed the inspection. The major reasons for rejection of sprayers included faulty pressure gages (43%) and nozzles (41%) with a incorrect flow rate, angle or type. The goal of the Belgium government is to have all crop sprayers (about 28,000) inspected before December 1998. In Belgium, the inspection fee depends on the length of the sprayer boom; ranging from 2500 Belgium Francs ($83) for sprayers with booms less than 12 m (40 ft) long to 4000 Belgium Francs ($132) for sprayers with booms greater than 22 m (72 ft).

Currently, only boom-type field sprayers have been subjected to mandatory inspection. However, plans are underway in both Germany and Belgium to expand this program to include high-pressure orchard sprayers.

SPECIFIC RESPONSES TO SOME KEY QUESTIONS IN THE QUESTIONNAIRE

Answers given by the survey participants to a small number of key questions are presented below. A complete set of survey questions and responses are given in the paper by Ozkan (1996). In addition to responses from European countries, information on Ohio's pesticide applicator training (PAT) program has also been presented below to provide a reference point for how pesticide applicators are trained in the U.S. It is important to note that although some common objectives and regulatory guidelines set by the USEPA and USDA have to be met by all states, some aspects of the PAT process in the U.S. vary from state to state. For example, the fee structure may be different in different states. Therefore, anyone interested in finding data for a specific state should contact the coordinator of the PAT program in that particular state.

A. Questions related to licensing and certification process

1) *What is the fee paid to get a license?*

Belgium	Free
Denmark	Free (must pay for courses taken prior to receiving the license)
Czech Republ.	$10
Germany	$200 to sell pesticides, $300 to apply
Italy	$10
Norway	$170
Spain	Free
Sweden	$115-$220
U.K.	$150
Ohio, U.S.A.	Commercial applicators must pay a license fee annually. This ranges from $20 for Public Operators (working for city/state/federal government) license to$100 for a Custom Applicator (owner, manager of a business) license. Private applicators do not purchase a yearly license. A $30 certification fee is paid upon passing examinations and at beginning of each 3 year certification period.

2) *How long is the license valid?*

Belgium	No expiration
Denmark	No expiration
Czech Republ.	No expiration for University educated, 5 years for others
France	5 years
Germany	No expiration
Italy	5 years
Norway	10 years
Spain	5 Years
Sweden	5 years
U.K.	No expiration
Ohio, U.S.A.	The minimum certification period by law nationally is 5 yrs. Some states like Ohio have shortened the time period. License is valid for one year for commercial applicators. Certification is required every 3 years for both private and commercial applicators.

3) *Is the license valid only for a particular application type or equipment?*

Belgium	Special license depending on the type of pesticide applied
Denmark	No, one license for field applications
Czech Republ.	No, one license for all applications
France	No license needed to apply
Germany	No, one license for all applications
Italy	No, one license for all applications
Norway	No, one license for all applications
U.K.	Foundation test + test(s) for specific equipment
Ohio, U.S.A.	No, one license for all applications

B. Questions related to educational programs conducted to train applicators.

1. *Length of educational programs? (Hours, days, etc.)*

Belgium	120 hours
Denmark	72 hours
Czech Republ.	Varies
France	150-200 hours
Germany	3 days for sellers of pesticides; 4 days for applicators
Italy	20 hours
Norway	3 days
Spain	Basic, 20 hours; advanced, 60 hours; special applications, another 25 hours
Sweden	3-4 days (depending on hazard classifications)
U.K.	2 days and upwards
Ohio, U.S.A.	Varies from state to state. In Ohio, One hour core material training, half hour for each category certified; then build up to a minimum 5 hours at the end of third year with more of the same or any approved course. Private applicators need 1 hour of core, then build up to a minimum of 3 total hours of training. Attending to these educational programs for recertification is not required. At the end of 3 year period, the applicators either must take the test and pass, or in lieu of retesting, they may attend educational sessions.

2. *Are there specific sessions in the programs for different types of application equipment/methods*

Belgium	No at this time; discussions are underway to provide separate programs for different equipment
Czech Republ.	No
Denmark	No, only one category concerning field spraying
France	No
Germany	No
Italy	No
Norway	Yes (Categories: conventional field crop sprayers, orchard, greenhouse, forestry, nursery, general)
Spain	No (Applicators can choose either the basic or the advanced session.)
Sweden	Yes (two general sessions; seed treatment and general application. Those in the general application group are further subdivided into small groups such as agriculture, horticulture, nursery, parks etc., but they all receive the same types of course work, lectures, etc.)
U.K.	Yes
Ohio, U.S.A.	No

3. *Who is in charge of providing educational programs to pesticide applicators?*

Belgium	Professional associations and government personnel organize; researchers, scientists, professors from universities teach.
Denmark	Agricultural colleges, business schools and centers for labor market courses.
Czech Republ.	Personnel from government research institutions and universities.
France	Agricultural college (high school) teachers, personnel from Ministry of Agriculture, Division of crop protection.
Germany	Plant Protection Office of the Chamber of Agriculture
Italy	Personnel from Regional government offices, private organizations, university
Norway	Local personnel, but these people receive training at the University periodically
Spain	Agriculture Dept. of the regional government has overall responsibility. Others such as application specialists from private and other government organizations and universities.
Sweden	Provincial government personnel, sometimes with help from University personnel
U.K.	University instructors, and private people who receives training periodically at Universities.
Ohio, U.S.A.	Cooperative Extension Services housed in Public Universities.

4. *Are the participants required to take a test to receive the applicator license? If _yes_:*

a) *How is the test given (written, oral, combination of both)*

b) *Duration of the test (hours?)*

c) *Does everyone take the same test? (If _no_, explain what types of tests are there, and who takes what type of test?*

Belgium	Yes. A 30 to 40 minute oral exam given by the Dept. of Public Health on topics associated with the type of application the person will be engaged in.
Denmark	Yes. Written and practical tests that take 2-3 hours. Everyone takes the same test.
Czech Republ.	No test given
France	Yes. A combination of written and oral test is given. Every one takes the same test.
Germany	A one-hour test is given. This includes an oral portion that is about 30 minutes long for applicators, 15 minutes for sellers of pesticides. Sellers are not asked questions related to application technology.
Italy	Yes. A 30-minute written test is taken by all applicators.
Norway	Yes. A one-hour written test is taken by applicators. Test questions are different depending on the specialty area of the applicator (Field sprayers, orchard, greenhouse, nursery, forest, etc.)
Spain	Yes. The same one-hour written test is taken by all.
Sweden	Yes. The same two-hour written test is taken by all.
U.K.	Yes. The test is mainly oral and last from a half day to a day. The participants are required to take a test for each equipment they will be using when applying pesticides.
Ohio, U.S.A.	A test is not needed to obtain a license, but it is required for certification. Every state is different in how categories are dealt with for commercial applicators. In some states, private applicators are not given written exams particularly for categories. Some states have open book exams. In general, within a given state all commercial applicators would take the same core material test and then they usually have to take a category exam that relates to the type of target crop/pest situation they will be working in.

Many states have categories for some specialized application methods such as aerial, fumigation and chemigation. In Ohio there are 33 categories commercial applicators can be certified for. For private applicators, if they are tested, most states only test on core topics not categories or only a few categories such as agricultural plant or agricultural animal. In Ohio written tests are given in 13 categories. In addition, everyone takes the same core exam.

C. Questions related to duration of a license and renewal procedures

For how long is the license valid? If renewal of licenses is required:

1) *Are applicators required to attend educational programs*
2) *Are the educational programs for license renewal different than the ones attended by the first-time licensees?*
3) *Are applicators required to take a test again?*
4) *Is there a fee associated with renewing the license (if _yes_, how much)?*

Belgium	License renewal is not required currently. Discussions are underway to make license renewal a requirement for those who wish to keep their licenses valid.
Denmark	License renewal is not required.
Czech Republ.	License is valid forever for people with a university degree. For others it is valid for 5 years. For renewal, participation in educational programs and taking a test are required. Test educational programs and the test given are the same as those for new applicators. A fee is paid for renewal ($10).
France	Renewal is required every 5 years. Participation in some educational programs or a test are not required. Fee required.
Germany	License is valid indefinitely. Renewal is not required.
Italy	License is valid for 5 years. Educational programs for license renewal are five hours shorter in total duration than the programs for new applicators. Applicators take the same test the first time they receive their licenses and for renewal. The fee for renewal is $10.
Norway	Renewal of a license was not required until recently. Currently a license is valid for 10 years. Participation in educational programs is required. Level of instruction and the fee have not been determined yet.
Spain	The license is valid for 10 years. Teaching material is updated periodically. Applicators take the same test the first time they receive their licenses and for renewal. Also a medical test is given with special attention given to the level of Acothil-Colinostheraso level in the blood. No fee is required for renewal.
Sweden	License is valid for 5 years. For renewal applicators must attend a 1-day course and pass a test which is the same they have taken when obtaining the license the firs time. The fee is $29.
U.K.	License is valid indefinitely. Renewal is not required
Ohio, U.S.A.	Licensing and certification are separate for commercial applicators. They may choose to pay for a license every year but their certification may be valid for 3-5 years.

RECOMMENDATIONS TO IMPROVE QUALITY OF PESTICIDE APPLICATOR TRAINING PROGRAMS IN TAIWAN

1. The policies governing PAT programs and the content of educational programs should be reviewed. The review committee should include people who are knowledgeable about the PAT programs around the world, and representatives from organizations and Extension Personnel who teach subjects related to pesticide application technology.
2. Emphasize hands-on training in educational programs. Teaching sprayer calibration in a classroom setting has not been effective.
3. Provide additional resources, especially personnel for delivering hands-on training.
4. Those who will be actually applying pesticides and using the application equipment must pass two exams before they are given an applicator license. The first exam should be a written exam to test applicators, general knowledge level on pests, pesticide formulations, safety and environmental concerns, and other pertinent topics. The second exam should include both a written part covering topics associated with efficient use of application equipment, and an oral part focusing on hands-on trouble shooting and equipment calibration.
5. Hands-on training and exams related to application equipment should be conducted by individual "private trainers" perhaps under limited government/university supervision. The "trainers" could be Extension personnel, technical representatives and dealers from chemical and sprayer companies, and others with sufficient training in sprayers and spray technology.
6. Trainers should be licensed, and keep their license current by periodically attending training programs offered by "Master Trainers" (Extension Specialists and others from state regulatory agencies, equipment and chemical companies). This type of "train-the-trainer" concept used in some European countries should be carefully reviewed and adopted if found applicable to conditions in Taiwan.
7. High-quality in-service training programs should be offered to "trainers" and regional PAT educators frequently but not less than once a year.
8. A standard fee across Taiwan should be set for the "trainers" to charge each applicator receiving training from the "trainer", and for administering the oral (hands-on) segment of the examination process. Although it is preferred that this program be self supporting, some economic incentives or subsidies could be provided by the state and federal agencies to the applicator who is willing to complete a rigorous training and examination process.
9. The fees should be kept at a level that can sustain high-quality educational programs.
10. Educational programs related to spray technology and equipment calibration should be hands-on and conducted outdoors.
11. The applicators should be required to attend a comprehensive educational program every third year to keep their license valid. However, if a separate equipment session and exam are to be held as described above, then the

applicators should be required to take this separate equipment session/exam every six years instead of every three years.

12. If personnel at regional Research and Extension Stations are given responsibility for educating pesticide applicators, at least one person in each Station should be assigned as leader for PAT educational programs. If these specialists are asked to carry out a wide range of educational programs, including PAT programs, in their regions, there will not be enough time left for any one educator to implement quality hands-on sprayer technology training sessions for applicators.
13. Instead of the mandatory equipment inspection programs implemented in some European countries, we should put more emphasis on educating applicators and letting them make sound management decisions when they apply pesticides. Adding a special hands-on application technology session (such as field days, sprayer "calibration clinics") to ongoing educational programs is likely to be a more productive, cost-efficient and a less bureaucratic method to reach the same goal.

CONCLUSION

Growing concerns about pesticide contamination of ground water and higher chemical costs make accurate application of pesticides increasingly important. Therefore, it is vitally important that pesticides be applied by trained and licensed operators. Applicators must receive strong educational training before they are awarded their license to apply pesticides. To teach efficient application of pesticides and proper operation of application equipment, we have to increase the time allocated to application equipment related topics in regional training programs. Educational programs should include hands-on training, conducted by knowledgeable teachers, in small-group settings. European and U.S. procedures for applicator education and inspection of application equipment should be carefully reviewed, and procedures found suitable for conditions in Taiwan should be revised if necessary, and adopted.

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改良適用於台灣農藥施噴人員訓練課程的建議

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摘要

本文包括了基於一些西歐國家與美國核發執照與訓練程序而改良適用於台灣農藥施噴人員訓練課程的建議。文中也提到了新歐洲共同體自發性的對於農藥噴灑機具強制性的檢驗與認證。

在美國使用農藥僅限於有認證過的施噴人員，或是在有認證過施噴者直接監督下的人員。認證過的施噴人員是通過筆試以顯示他們具有農藥使用的知識以及已經符合其他核發執照的資格。執照更新的程序在美國不同於西歐國家。美國許多州需要每三年換發執照。一些歐洲國家並不要求再認證，然而也有若干其他國家最近已採行再認證的觀念以及隨著再認證程序而來的延續教育。

在美國與一些西歐國家間核發執照給施噴人員程序上最重要的一項區別在於發照前施噴人員知識等級的測驗。大多數歐洲執照的應考人必需通過一項一對一的口試，以及筆試外之現場解決問題的過程。為了改良成在台灣適用的農藥施噴人員訓練課程，歐洲與美國施噴人員的教育程序和噴灑機具的檢驗都要仔細地評估。如有必要，找到適合台灣條件的程序後還要加以修改再採用。

前言

全世界生產的農藥約有三分之一銷售到美國。農藥工業的營業額在 1992 年達到了八十億美元。地下與地表受到農藥污染已漸受關切以及化學成本的增加使得準確噴灑農藥較以往來得更重要。農藥的影響受到施噴方法與時間、以及所用機具操作與精度的影響極大。噴灑過少的農藥對於蟲害防治效果不彰，因而可能需要增加再行噴藥的成本。施噴過量的農藥會增加成本，可能會傷害作物，也可能會導致環境污染。農藥容器上面的標籤指示了正確的施噴率。然而祇有在施噴機具能勝任工作、經常校正與正確操作下纔能達到這樣的施噴率。

在美國正規的準則指明施噴率應在標籤建議值的5%以內。雖然在真實世界的情況是否能達到5%誤差範圍的施噴準確度仍有存疑，在施噴準確度上做改進是需要的，而且藉著正確選擇、校正與操作施噴機具來完成。為了獲得農藥施噴如此高的準確程度，需要有受過良好教育與有資格的人員來噴灑與處理化學藥劑。

雖然在美國與西歐國家實施的教育計畫形式上可能有差異，但是所有施噴人員都有教導如何正確的操作與校正施噴機具，和採用最有效的方式施噴農藥。雖有些國家施噴農藥並不需要執照，但包括美國的其他國家是需要噴灑某種等級農藥的執照。獲得執照的條件在美國各州和全世界各個國家都不一樣。

直到最近，一些西歐國家已向前邁進一步地實施認證施噴機具的程序。無法通過檢驗的噴藥機械不得使用來噴灑農藥。機具檢驗的規定各個國家不同。有些歐洲國家卻反對這些規定。

目的

在台灣為實施新的農藥施噴教育計畫與改進現有的教案，須要仔細評估全世界其他國家所遵循的程序。本文目的在於：

1) 彰顯美國與西歐國家在農藥教育與發照程序方面的共通性與比較。
2) 提供有關新歐洲共同體自發性地對於農藥噴灑機具的檢驗與認證的資訊。
3) 提出最近在台灣農藥施噴教育計畫改善品質的一些建議。

過程

為了獲得歐洲農藥施噴人員教育和噴灑機具檢驗計畫的資訊，原作者曾寄一份問卷到下列國家：比利時、捷克、法國、德國、義大利、荷蘭、挪威、西班牙、瑞典與英國。參與這份調查的人是挑選過的，因為他們直接與農藥施噴人員教育計畫有關，或是至少有資格去回答這些問題。為了澄清一些問題的答案，有再一次與填卷人，不論是面對面、或是藉電話、傳真與網際網路來連繫。

美國與歐洲國家訓練農藥施噴人員與檢驗噴灑機具的摘要陳述於下。關於在美國的這些計畫，以及歐洲填卷人各項問題回答的細節參見原作者的報告。一些關鍵性問題的特定結果在本文會提到。

重要發現的摘要

a) *在美國與西歐農藥施噴人員的教育*

有關噴藥機具的教材與進度在美國各州皆不同，全世界各國也不一樣。在美國各州的訓練課程必需符合聯邦殺蟲劑殺菌劑復元法案(FIFRA)所建立的最低要求，許多州都有比聯邦法律更嚴格的農藥法規。

在美國，一些農藥會對於大眾健康與環境造成危害，因此被歸類為「限制使用」其他農藥則被歸類為「一般使用」。限制使用的農藥祇能給有認證的施噴人員使用，或是在一位有認證施噴者監督下的人員。認證過的施噴人員是通過筆試以顯示他們具有農藥使用的知識以及已經符合其他核發執照的資格。這些訓練教材包含核心課程(安全、環境、法規、農藥廢棄物管理、機具校正等)和特定作物以及與認證類別有關的課題(農藝作物、園藝與裝飾作物、水產蟲害防治、家庭蟲害防治)。施噴人員必需參加至少五個小時的教育課程，其中需包括至少一小時的核心課程與半小時施噴人員擬認證類別的訓練。

正確操作與校正農藥噴灑機具乃所有施噴人員為了要準確施噴農藥期待獲得整體知識的重要部份。一般來說，美國農藥施噴人員教育計畫為全世界許多國家所羨慕，但是與施噴機具選擇、操作與校正有關的課程卻未受到重視。

雖有些國家適當的強調主題，但多數其他國家僅分配三十分鐘花在施噴機具課題上。此種訓練過程通常變得沒有效果。許多情況是參與演講導向教學課程的大半聽眾無法和授課者相互溝通。甚至有些情況係採用幻燈片與錄影帶的教學方式，而授課者沒有回答問題。訓練程序沒有促起施噴人員去校正他們的噴藥機械。

施噴人員獲得認證前參加的筆試並不是其具備正確操作、維修與校正施噴機具知識的指標。例如，俄亥俄州商用施噴人員的考試包含核心課程的八十個問題，以及應考者選定特定類別的二十五至三十五個問題。在這將近一百一十個題目中，沒有超過十題直接或間接與施噴機具有關。大多數的試題，例如混合藥劑、飄移、噴頭選擇，正確清理噴頭、校正理由、正確清洗噴藥機械等，都能夠用一般常識即可回答。由於 65%係及格標準，應考者可不答與機具有關的題目而仍就成為一位認證過的農藥施噴人員。這種情況不限於在俄亥俄州。為訓練農藥施噴人員所傳授的教育課程與施噴者考試的內容各州差異不大。

另一方面，一些歐洲國家要求的考試包括一項在認證農藥施噴人員取得等第前，直接一對一的噴藥機具測驗。在這種現場考試之前，施噴人員必須上過有教受噴藥機操作與校正的基本原理，以及正確使用農藥的學校。這些學校根據施噴人員的經驗，開設持續一至四天的課程。

另項與美國核發施噴者執照有關的是祇有監督人員需持有一有效的執照。

在其監督下，無執照者可以處理農藥與操作噴藥機具。此乃假設監督人員在噴藥前可提供適當的訓練給其受僱者。如果有足夠的監督，這項政策就屬適當且能成功。不幸的是，並沒有辦法曉得監督人員是否適當地訓練操作者。在許多歐洲國家，實際從事農藥施噴的每一個人必需擁有一個有效的施噴人員執照。

執照更新的程序美國不同於西歐國家。很多美國的州其執照必需每三年換發一次。申請人不是需要參加筆試且及格、就是要參加一項至少五個小時的教育課程。在這種有層次的教育課程中，施噴人員可獲得各種蟲害防治的最新資料。直到最近，在歐洲纔需要操作人員的再認證。過去一旦取得執照，則終身有效。雖有些歐洲國家仍不要求再認證，其他國家已接受再認證與伴隨再認證程序而來的延續教育的觀念。

b) 施噴機具的檢驗與認證

本調查所含蓋的國家其實施志願性的機具檢驗計畫已有數十年。農藥施噴人員參加層級的降低與濫用農藥引起公眾關切的俱增，迫使一些國家的立法者增訂更嚴格的法規來管理施噴機具的情況。德國與比利時分別自 1993 年和 1995 年起強制執行機具檢驗。如果一台噴藥機通過強制性檢查，即有一張蓋有管理機關認可圖章的貼紙粘在噴藥機上。典型的檢驗包括有：噴藥機一般情況(接頭、軟管、洩漏、噴桿穩定性、泵、噴頭等)、噴頭處壓力穩定性、壓力錶狀況、各噴桿壓力偏差、關掉任一噴桿時噴頭處壓力變化、所有噴頭流量、和噴藥機監視器與控制單元準確度。

在比利時強制檢驗施行的頭一個月，有 1556 輛噴藥機受檢，其中約有 87% 通過檢驗。無法通過的主要原因包括：壓力錶(43%)故障、以及噴頭(41%)不當的流量、角度和型式。比利時政府的目標是在 1998 年 12 月前將所有的作物用噴藥機(約 28,000 台)檢驗完畢。在比利時，檢驗費用係根據噴桿長度而定；範圍在 2500 比利時法郎(83 美元)—桿長小於 12 公尺(40 英吋)與 4000 比利時法郎(132 美元)—桿長大於 22 公尺(72 英吋)之間。

近來，祇有桿式平地田間噴藥機需要強制受檢。然而在德國與比利時兩國家，已打算將此計畫擴展到高壓果園噴藥機。

在台灣改進農藥施噴人員訓練(PAT)課程品質的建議

1. 管理 PAT 計畫的政策和教育課程的內容應加以評估。評估委員會應包括通曉全世界有關 PAT 計畫的人員、以及教受有關農藥噴灑技術項目的組織代表和推廣人員。
2. 教育課程中強調現場訓練。在教室內講解噴藥機校正是沒有效果的。

3. 提供額外的資源，尤其是傳受現場訓練的人員。
4. 實際噴灑農藥與使用噴藥機具的人在他們取得執照前必需通過兩項測驗。第一項筆試測驗施噴者在蟲害、農藥形成、安全與環境有關事項、以及其他相關主題的知識。第二項測驗應包括與施噴機具有效使用有關課題的筆試部份，與著重現場故障排除和機具校正的口試部份兩者。
5. 與噴藥機具有關的現場訓練與測驗，或許在政府／大學監督之下，由個別的民間訓練師來執行。訓練師可為推廣人員、技職代表、化學藥劑與噴藥機經銷商、以及其他具有噴藥機械與施噴技術專業訓練的人士。
6. 訓練師應有執照，且需定期參加由資深訓練師(公家督導機關、農機具廠商與化學藥劑公司的推廣專家或其他人士)所提供的訓練課程以維持他們的執照效期。此種在一些歐洲國家施行的訓練訓練師觀念應仔細地評估，而採納在台灣能適用的情況。
7. 高品質在職的訓練課程應經常提供給訓練師和地區性的 PAT 講師，惟一年不得少於一次。
8. 在台灣收費標準應考慮到給付給訓練師的部份，因要負擔每位施噴人員由訓練師處所得到的訓練，以及測驗過程中實施口試(現場)的部份。雖然本計畫傾向於自給自足的方式，但地方政府與中央機關若能對有意願完成嚴格訓練與測驗過程的施噴人員給予經濟上的獎勵或補助則更佳。
9. 收取的費用應能維持一定高品質的教育課程。
10. 有關噴藥技術與機具校正的教育課程應在戶外實施。
11. 施噴人員每三年需參加一項綜合性的教育課程以維持其執照的效期。然而，若是個別機具部份與測驗如上所述地維持，則施噴人員每六年而非每三年需要參加此個別機具的課程與測驗。
12. 如果地區性的研究與推廣場所有人員負責教育農藥施噴者，則每一場所至少要指定一人做為 PAT 教育計畫的主管。若這些專業人士在當地負責多項教育業務，包括 PAT 計畫，那麼他們很有可能沒有足夠的時間留給任何一位講師去為施噴人員提供有品質現場噴藥技術的訓練課程。
13. 若不採取一些歐洲國家所實施的強制噴藥機具檢驗計畫，則應將重點置於教育施噴人員以及當他們噴灑農藥時，讓他們有健全的管理決策。增加特定的現場噴藥技術課程(例如田間課程、噴藥機校正與診斷)到現有的教育計畫似乎是一種可達到相同目標、而較有建設性、節約成本、和較少官僚主義式的方法。

結論

農藥污染地下水受到的關切與日俱增以及較高的化學藥劑成本使得準確施噴農藥的重要性增加。因此，要有訓練過且有執照的人員來施噴農藥是相當重要。在施噴人員取得噴灑農藥執照前，必須獲得完善的教育訓練。為了要教導有效的施噴農藥和正確的操作噴藥機具，在地區性的訓練課程內必需增加噴藥機具相關課題的時數。教育計畫應包含在有經驗教師指導下以小組方式的現場訓練。歐洲與美國的施噴人員教育與噴藥機具檢驗的程序應仔細評估，倘發現有適合台灣情況的部份應可採納，或是做必要的修改。

綜合討論題綱：

1. 臺灣病蟲害防治機械與技術之未來研究方向？

提問來訪專家之問題：

依兩位專家之意見，臺灣病蟲害防治機械與技術之未來研究方向為何？目前最迫切之研發重點何在？請建議應如何進行才能事半功倍地完成您們所認為之研發重點？

2. 如何以團隊合作方式進行病蟲害防治機械與技術之研發工作？

提問來訪專家之問題：

在對臺灣病蟲害防治機械與技術之現況有所了解之後，您們是否有意願或可能與臺灣進行雙方之合作研究？倘有合作研究之機會，您們最感興趣之研究主題為何？

3. 臺灣應有怎樣的制度來管理施藥機械之測定與認證，以及施噴人員之證照與教育？

4. 臺灣是否適合發展精耕農業(precision farming)？可能的應用目標應定在那裏？

提問來訪專家之問題：

以美國目前使用精準農業之經驗而言，臺灣之小農耕種方式有需要走向這種高科技、高成本投資之栽培體系嗎？

其他提問來訪專家之問題：

1. 臺灣在環境保護需求日益殷切下，在有機農法栽培上漸有使用植物性抽取油(例如除蟲菊 Pyrethrum)作病蟲害防治，而在生物防治上也有像蘇力菌(Bacillus Thuringiensis, BT)等生物性製劑之使用需求，不知美國是否也有類似非農藥性製劑施用之情形？您們的作法如何？與現行傳統之農藥施用技術有何差異？
2. 依兩位專家之意見，生物防治與化學施噴防治何者為重？請就現在與未來之可能發展作說明。

農藥施噴品質量測與管制研討會籌辦人員：

召集人：林所長俊義

籌辦主任：梁主任連勝

聯絡人：蔡副研究員致榮

一、總務組：

負責餐飲、點心、講座紀念品、會場橫幅、講座插花以及錄影(音)帶之訂購，團體合影之規畫，並管理經費之運用與酬勞費之核發

(組長—蔡致榮，組員—魏阿娟)

二、文書組：

負責研討會通告之準備、函寄，論文集之編訂與印刷，以及與會人員名牌與會場位置圖之製作，以及研討會綜合討論之記錄

(組長—楊智凱，組員—曹之祖)

三、會場組：

負責會場之佈置與標示，多媒體視聽器材(含錄影帶放映機、兩套幻燈機與螢幕，以及 16mm 電影放映機)之借用、安裝，以及茶會場服務(茶水、點心與便當之供應發送)

(組長—顏秀榮，組員—羅慶滿、莊大山)

四、接待組：

負責人員接待、報到、會場資料之分發

(組長—陸龍虎，組員—邱相文、簡文章、黃悅真、胡絜滿)

五、錄影組：

負責協助各場專題演講與綜合討論之現場照相與錄影

(組長—周廷弘，組員—黃國祥、柯平福

技術室—陳盈佑、盧文琪)

台灣省農業試驗所

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